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CONTENTS

Number 45

A. S. THOMAS: The Wild Coffees of Uganda. With Plates 1–4 1

R. E. MOREAU: The Yield and Maturity Period of Potatoes (*Solanum Tuberosum*) at Low Latitudes 13

W. S. MARTIN: Grass Covers in Their Relation to Soil Structure. With Plate 5 21

H. L. RICHARDSON, S. T. HWANG, C. L. FENG, S. H. TSU, and S. H. YUAN: The Use of Organic and Inorganic Manures with Rice: A Continuous Factorial Experiment 33

T. ASHTON: The War-time Feeding of Concentrated Food to Pregnant Rabbits 51

R. O. DAVIES, T. W. FAGAN, and J. L. JOHN: Requirements of the Potato on Acidic Bracken Land . . 54

Number 46

B. P. PAL: The Pusa Wheats: The Wheat-Breeding Work of the Imperial Agricultural Research Institute . . 61

N. J. SCORGIE and WM. C. MILLER: Further Investigations on the Alleged Toxicity of Cod-liver Oil for Pigs . . 74

H. B. WATERS: Agriculture in the Gold Coast . . 83

F. B. SHORLAND, R. HANSEN, and K. J. HOGAN: Studies on the Fats of the Bacon Pig with reference to Carcass Quality. I. Iodine Value of the Back Fat under Different Conditions of Feeding 103

166676

Number 47

H. A. TEMPANY, G. M. RODDAN, and L. LORD: Soil Erosion and Soil Conservation in the Colonial Empire. With Plates 6–9 121

JOHN HAMMOND, JNR.: Correction for Time of Service in Lactation Records for a Fixed Period 154

A. R. SAUNDERS: Efficiency of Design in Field Experiment at Potchefstroom, South Africa 157

F. YATES, D. A. BOYD, and I. MATHISON: The Manuring of Farm Crops: Some Results of a Survey of Fertilizer Practice in England 163

Number 48

T. EDEN: Studies in the Yield of Tea: Part V. Further Experiments on Manurial Response with special reference to Nitrogen 177

A. S. THOMAS: Observations on the Root-systems of Robusta Coffee and other Tropical Crops in Uganda. With Plate 10 191

M. H. FRENCH: Development of Livestock in Tanganyika Territory. VI. The Development of Mutton Qualities in Masai and Grade Black-headed Persian Sheep . . 207

J. ANSEL ANDERSON: Canadian Research on Malting Barley. Part I. Malting Tests and Qualities. With Plate 11 . 219

463
6663

THE WILD COFFEES OF UGANDA

A. S. THOMAS

(*Department of Agriculture, Uganda*)

With PLATES 1–4

THE Uganda Protectorate is situated on the central African plateau, most of it lying between longitudes 30° and 35° E. and latitudes 4°N. and 1° S. As the country is on the equator and is close to Lake Victoria, much of it enjoys a good rainfall, averaging 40 to 60 in. a year. The total amount is not large, but in many places the rain is very well distributed throughout the year; the two main wet periods are at the times of the equinoxes, but it is seldom that four or six weeks pass without some rain. The average temperature over most of the protectorate is between 65° and 75° F., for most of Uganda is at altitudes of 3,000 to 5,000 ft. above sea-level. The general slope of the land is towards the north where, on the borders of the Anglo-Egyptian Sudan, the rainfall is more sparse and the temperature is higher than in the vicinity of Lake Victoria.

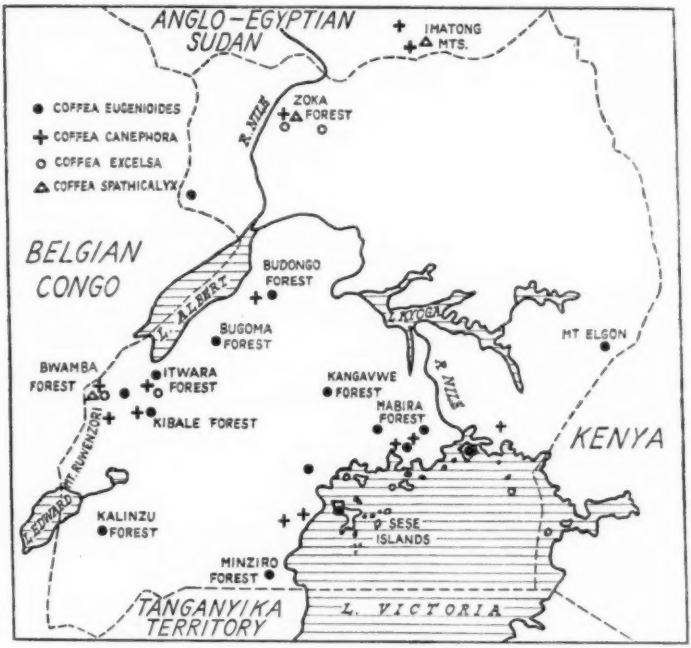
Under such conditions of equable temperature and well-distributed rainfall it might be expected that there would be large stretches of forest; but there has long been intense human settlement throughout Uganda and the trees have been cut down and burnt; at the present time most of the country-side is covered with grassland or open woodland, the closed forest being confined to less than 3 per cent. of the total land area. It is in these forests that the wild coffee plants are growing. Four species of Coffea are known to be wild in Uganda—*C. eugenioides* S. Moore, *C. canephora* Pierre, *C. excelsa* A. Chev., and *C. spathicalyx* K. Schum.; they are described in that order, the order of the frequency with which they occur.

Coffea eugenioides

The map shows that this species has been found in many parts of the country, for it is not confined to the large forests, but is growing in many of the small relict forests on hills in Buganda; these forests have persisted because they are on places too rocky for clearing and cultivation to be worth while. *C. eugenioides* appears to stand drought better than any of the other wild coffees in Uganda. There is rapid percolation through the steep stony soils of the hill-side forests and conditions become very dry at some times; in spite of the overhead shade, all the plants in the undergrowth are wilted during the dry seasons. *C. eugenioides* is intolerant of very wet conditions; it occurs in forests such as the Minziro Forest, some parts of which are very wet; but the coffee is restricted to the higher slopes, which are never waterlogged. In this respect it differs from *C. canephora*, which is often more abundant in the hollows; in some localities the two species grow in close proximity, but usually the *C. eugenioides* is in drier areas than those in which *C. canephora* is growing; a striking example of this difference in habitat

is to be seen in the Budongo Forest, where *C. eugenioides* is more abundant in the drier eastern side, whilst *C. canephora* is more abundant in the wetter western side of the forest.

C. eugenioides appears to be tolerant of a wide range of soil reaction, another respect in which it differs from *C. canephora*; the former grows wild on soils which are slightly alkaline, neutral, or definitely acid, with a reaction as low as pH 4·5; the latter does not usually grow wild on



The Uganda Protectorate showing distribution of wild coffees.

any very acid soils. There is one other difference between the distribution of the two species—*C. eugenioides* often grows near the edge of the forests but, as a rule, *C. canephora* is more abundant at some distance inside.

The composition of Uganda forests varies greatly for, as Dawe [1] pointed out, 'almost every forest in Uganda possesses a character peculiarly its own, given it by the predominance of one or two particular trees'; it is not possible, therefore, to correlate the distribution of *C. eugenioides*, which grows in all the larger forests, with that of any large tree species; and, in most of the relict small patches of forest in which the coffee is growing, many of the bigger trees have been cut out for timber. *Albizzia zygia* Macbride, *Sapium ellipticum* Pax., and *Teclea nobilis* Del. are common species, typical of secondary forest-growth, which are found in these relict forests.

Eggeling [2] has omitted *C. eugenioides* from *The Indigenous Trees of the Uganda Protectorate* as it seldom grows larger than a shrub. But the largest specimens may definitely be classed as small trees, growing to a height of 15 ft. and having a well-defined trunk about 3 in. in diameter (Plate 1, fig. 1). Such large specimens are not common; the species usually is found in the form of a shrub, 6 to 10 ft. in height, with more than one main stem. When the plant is growing under shade the leaves resemble those of *C. arabica* and sometimes are nearly as large, but usually they are smaller and much thinner; the average size of leaves of *C. eugenioides* growing in Uganda forests is about 3½ in. long and 1½ in. wide. The flowers also resemble those of *C. arabica*, but are much smaller and there are seldom more than two or three in a cluster. The fruits are not abundantly produced and contain a very small bean; the quality of the bean is mild and agreeable but, on account of the very small yields, they are not worth collecting from the forests; although the inhabitants of Uganda have a long tradition of utilizing the fruit of *C. canephora*, both from wild and cultivated plants, yet they have never paid any attention to that of *C. eugenioides*.

All species of coffee are greatly influenced by the intensity of the light under which they are growing and, in the case of *C. eugenioides*, the differences between plants grown in the open and in shade are especially marked. As described above, when this coffee is growing in its natural forest habitat, it is open in habit and resembles, in miniature, *C. arabica* in all its parts. But when *C. eugenioides* is planted in the open it assumes a very different appearance, becoming a compact conical shrub; the leaves are scarcely to be recognized as those of the same species, being small, narrow, and encurled: the length is only about 2 in. and the width ½ in. Wild plants from different forests show marked variations, but it is difficult to assess to what degree these variations are due to genetic factors and to what degree they are due to environmental factors; plants which have seemed to be outstanding in vigour and size of bean when growing in the forest have produced progeny which was in no way remarkable when in cultivation; and the yields have been so small as to be of no economic value.

C. eugenioides is to be found in other territories near the borders of Uganda; in the east it is abundant in the forests of the Nandi escarpment and the Cherengani Hills of Kenya; in the north it occurs in the Anglo-Egyptian Sudan; and in the west, it occurs in the Belgian Congo.

Coffea canephora

This is a most variable species and on that account several different names have been given to different forms—*C. Laurentii*, *C. robusta*, *C. arabica* var. *Stuhlmanii*, *C. bukobensis*, *C. Maclaudii*, *C. ugandae*, and *C. quillou*. This multiplicity of specific names, when applied to varieties, may lead to great confusion; the natives of Uganda apply the term 'nganda' to spreading forms, such as are called *C. quillou* in the Netherlands East Indies, where the name *C. ugandae* is applied to an erect form. This species, under the name of 'Robusta coffee', is an important crop

in the Dutch East Indies, in West Africa, in Uganda, and in the Bukoba district of Tanganyika.

C. canephora is widely distributed in Uganda, but does not occur wild in so many localities as *C. eugenioides*; it requires moister conditions than that species and therefore is seldom to be found in the relict forests near the tops of hills; there are exceptions to this rule—there is wild *C. canephora* as well as wild *C. eugenioides* in the forest on the hill at Mukono, 15 miles east of Kampala. It is probable that the Mukono coffee, and the coffee that is growing in many other scattered small forests, such as those in the valleys of the Masaka district, is an escape from cultivation or even a relict of former cultivation. Monkeys are fond of picking the ripening fruits, chewing off the sweet, succulent pericarp, and spitting out the seeds; they are without doubt responsible for much distribution of the coffee. Men, as well as monkeys, are normal constituents of the 'biome' or basic community unit of plants and animals in Uganda—in fact they are the dominants—and therefore it is a waste of time to try to decide in which localities the *C. canephora* is an escape and in which localities it has occurred without human intervention. There has been a long tradition of utilization and cultivation of *C. canephora* in Uganda; it is impossible to ascertain exactly how long the period has been, but it probably extends over some hundreds of years.

At the present time the greatest abundance of wild *C. canephora* in any locality of Uganda is that in the Kibale Forest, Toro, where large crops are picked each year under licence from the Forest Department. Stretches of *Cynometra Alexandrii* C. H. Wright occur in the Kibale Forest and appear to represent the forest climax; *C. canephora* does not grow in these places, but is always found in association with more soft-wooded trees, such as *Ficus mucoso* Welw., *Spathodea campanulata* Beauv., and *Markhamia platycalyx* Sprague. Typical shrubs in the undergrowth are *Whitefieldia elongata* C.B.Cl. and *Argomuellera macrophylla* Pax, whilst *Piper umbellatum* L., *Palisota Schweinfurthii* C.B.Cl., and the grass *Leptaspis cochleata* Thwaites are common herbs. The coffee is especially abundant, and in places it is dominant, in the undergrowth of hollows near the river Mpanga, which flows through the eastern side of the forest; these hollows are very wet, almost marshy, during the wet seasons. It is not surprising therefore that the root-system of the coffee is close to the surface of the soil; when the thin layer of mould on the soil is scraped away, a system of large horizontal lateral roots is disclosed, radiating in all directions; these roots and their branches appear to draw their nourishment from the forest litter rather than from the soil itself (Plate 1, fig. 2).

Chevalier [3] and Porteres [4] have noted the great variation to be encountered among the wild populations of *C. canephora*, even in any one locality; this variation is easily seen in the Kibale Forest. In the central part of the forest the coffee assumes the form of small spreading trees up to 25 ft. in height in the more shady places, but shorter and more spreading where there is not a dense overhead canopy; the trunks are up to 4 in. in diameter; the leaves are usually rather small and narrow,

a typical size being about 9 in. long and 3 in. wide; the fruits on most trees also are small. Leaf Disease (*Hemileia vastatrix*), the most important disease of Robusta coffee in Uganda, and Berry-borer (*Stephanoderes hampei*), the most important pest, are common on the wild *C. canephora* in the Kibale Forest and other forests of Uganda.

C. canephora also grows wild in the north end of the Kibale Forest, a part sometimes known as the Itwara Forest. The type of coffee in this locality is, however, very distinct from that growing a few miles to the south; it is erect in growth and has much larger and broader leaves, up to 11 in. long and 5 in. wide; the fruits, too, are larger. There are some patches of forest where the coffee completely dominates the undergrowth, casting so dense a shade that few plants except its own seedlings can grow beneath. Some of the soil on which *C. canephora* grows in the Itwara Forest is markedly acid, with a reaction of pH about 4·5, instead of the neutral or alkaline soils, with a pH value about 6·0 to 7·5, on which the wild coffee has usually been found. As a type of coffee tolerant of acid soils would be of great value for cultivation in Uganda, seed has been collected from trees which seemed to be outstanding in bean-size and the progeny grown at the Kawanda Experimental Station. The results have been disappointing, for the foliage of this type proved to be too delicate to stand exposure to full sunlight, and the size of the bean that was produced was very much smaller than that of the parent trees.

The root-system of the wild *C. canephora* in the Itwara Forest, like that in the Kibale Forest, is mainly close to the surface; the following table gives the length of roots in the soils at different depths, as shown by examination of a series of cores taken in a group of the coffee trees:

Depth (in.)	*Length of roots per cu. in. of soil (in.)*
0–3	12·5
3–6	3·3
6–9	0·9
9–12	0·9
12–15	0·6
15–18	0·4

These figures show that the length of coffee roots in the top 3 in. of soil was more than twice that of the roots in the 15 in. below. Inspection of wild coffee roots in other forests has shown a similar distribution; in every case, with the exception of the roots of *C. spathicalyx*, the bulk of the feeding-roots has been near the surface of the soil. Therefore, when the soil has been sampled to test its reaction, attention has been paid to the top few inches; the reaction has been tested in the field with B.D.H. Universal Indicator.

The Kibale Forest lies at an altitude of nearly 5,000 ft., and is the highest of the large forests in which the coffee has been found wild in Uganda, but an interesting form with short, broad leaves has been found on the lower slopes of Mt. Ruwenzori. On the other side of the mountain, close to the borders of the Belgian Congo, *C. canephora* grows wild at an altitude of only about 2,500 ft. in the Bwamba Forest. As

in the Kibale Forest, so also in the Bwamba Forest, areas of climax forest are characterized by the dominance of *Cynometra Alexandrii*, from which the coffee is absent: it is locally abundant in mixed forest of more quick-growing trees—*Spathodea campanulata*, *Markhamia platycalyx*, and *Chrysophyllum* spp. There is a great mixture of forms among the Bwamba Forest *C. canephora*: some trees have the spreading habit and the narrow encurled leaves, like the Kibale Forest coffee, whilst other trees have an erect habit and broad flat leaves like the Itwara Forest coffee (Plate 1, fig. 3). These differences are demonstrated by the measurements (in inches) of leaves on primary branches of adjacent trees, growing close together under similar conditions of light intensity.

Tree 1—leaves narrow, encurled			*Tree 2—leaves broad, flat*		
Length	*Breadth*	*No. of pairs of veins*	*Length*	*Breadth*	*No. of pairs of veins*
6·0	2·75	12	8·0	3·5	7
7·5	3·5	12	7·6	4·6	10
8·35	3·2	11	9·7	4·4	10
8·0	3·25	11	12·2	4·3	12
9·0	3·4	14			

These figures show how great are the differences between the leaves of adjacent trees and how great are the variations between the leaves along any one primary branch; in view of such diversity it is obviously a mistake to make differences in nomenclature based on the few leaves which are comprised in a herbarium specimen. The Baamba, a semi-pygmy tribe who inhabit this forest region, did not make any use of the wild coffee before the coming of European influence, although they now cultivate the crop in quantity; but this circumstance does not mean that the coffee may not have been brought there by man in the past, for near to the coffee are the two spots where the oil-palm (*Elaeis guineensis* Jacq.) is growing wild in Uganda—a distribution so local as to be a strong indication that it was introduced by man.

Another forest in which *C. canephora* is abundant is the Kasai Forest, which may be considered as an outlying portion of the Mabira Forest, north of Lake Victoria. As in other forests, there is marked variation among the wild-coffee population, but most of the trees are of the spreading type, with rather narrow leaves. The coffee in this forest is of great economic importance, as it is stated to be the source from which was derived much of the coffee cultivated by Africans in Uganda and in Bukoba. The inhabitants of the Sese Islands in Lake Victoria, an old centre of coffee cultivation, have a tradition that their coffee was derived from the Kasai Forest and from forests in the Masaka district, where it may be found wild in many valley forests, usually in such small patches as to seem probably an escape from cultivation. *C. canephora* has been found wild in one locality in Busoga, east of the Nile, near the shores of Lake Victoria, where it seems to have been a relic of former cultivation.

The Budongo Forest lies on the east side of Lake Albert and, from

the aspect of timber production, it is the most important forest in Uganda. There is wild *C. canephora* in this forest, but it is not so abundant as in the forests near Lake Victoria; Emin Pasha recorded that, about 1870, coffee was exported in quantity from Buganda, near Lake Victoria, to Bunyoro, the district in which the Budongo Forest is situated. The Budongo Forest *C. canephora* is mostly in the west of the forest and, as in the other forests, it is absent from the parts where the climax vegetation, which in this forest also is of *Cynometra Alexandrii*, is growing; it is associated with other tree species such as *Chrysophyllum* spp., *Alstonia congensis* Engl., &c. The coffee is mostly of a fairly spreading type, with leaves of medium width.

About 100 miles to the north of the Budongo Forest, on the east bank of the Nile, there is a small isolated patch of forest, usually, but incorrectly, called the Zoka Forest, for Zoka is the name of a river which flows through the forest and not of the forest itself, which is called Oju by the tribes living near it. This forest, which is only about 10 square miles in area, is at an altitude of only 2,500 ft., with a climate hotter and drier than that of the other Uganda forests but, as it lies in a hollow at the junction of the Zoka and Aluga rivers, there is no doubt that ground-water supplies are responsible for its persistence. *C. canephora* is abundant in parts of the forest, mostly in hollows near the rivers, growing on loamy soils which are inundated at certain times of the year. Above the trees of *C. canephora* there is a high irregular canopy of large trees—*Khaya grandifoliola* C.DC., *Chlorophora excelsa* B. & H., and *Pterygota* sp.; *Teclea nobilis* is associated with the coffee in the understory. *C. canephora* is locally dominant in some places; it exhibits the usual variability, but is mostly of narrow-leaved spreading type; in parts where the shade is dense, the growth is more erect and the leaves are broader. Instead of growing inside the forest, as is the rule in other localities, the coffee is near to the edge of the Zoka Forest; this phenomenon may be explained by the fact that the edges of the Zoka Forest are rapidly receding on account of the activities of elephants, which abound in the Gulu elephant sanctuary, where the forest is situated. Not only do the elephants directly damage the trees, but also, by breaking the canopy, they encourage the growth of grasses and the incursions of the annual fires which kill off more trees.

The Zoka forest is the most northerly locality from which wild *C. canephora* has been reported from Uganda, but the species is abundant in the valley forests of the Imatong Mountains, just over the border of the Anglo-Egyptian Sudan. The growth of *C. canephora* in these forests was reported by Chipp [5]. The largest forest is at Lotti, and resembles the Zoka Forest, which is only about 100 miles away, having *Khaya grandifoliola*, *Chlorophora excelsa*, and *Alstonia congensis* as common tree species. The *C. canephora* is of a broad-leaved erect type; the biggest specimen seen was 20 ft. high, with a trunk nearly 6 in. in diameter. At Thallanga Forest (which was not visited by Chipp) the coffee is also of erect habit with leaves of a medium width. The Laboni Forest, which lies to the south-west of the mountains and is only a mile or two from the border of Uganda, is of a lower, more

open type than the other two forests; *Kigelia aethiopica* Decne and *Chrysophyllum albidum* G. Don are common trees. Some of the specimens of *C. canephora* in this forest were larger than any seen wild in Uganda, although some old trees in native gardens are even larger. The biggest specimen seen at Laboni had a height of nearly 30 ft., a spread of over 35 ft., and a trunk nearly 1 ft. in diameter. There was the usual variation among the wild-coffee population but, on the whole, they were of a narrow-leaved type, some having leaves only 6 in. long and 2 in. wide—much smaller than those of any wild *C. canephora* trees seen in Uganda.

The forests at the base of the Imatong Mountains in which *C. canephora* was seen to be growing wild had surface soils of reddish or brownish loams, neutral or slightly alkaline in reaction. Most of the feeding-roots of the coffee were in the top few inches of the soils and not in the subsoils, which were more acid in reaction. It appears that wild *C. canephora* does not grow in the Sudan east of the Imatong Mountains; on the Boma plateau in the extreme south-east of the territory wild *C. arabica* is abundant [6]. *C. canephora*, however, has been reported from more than one forest on the west bank of the Nile, in the south-west of the Anglo-Egyptian Sudan.

Coffea excelsa

This species has been found in four localities of Uganda—the Bwamba Forest, the Itwara Forest, the Zoka Forest, and in riverain forest near Killak to the east of the Zoka Forest.

The finest specimens of *C. excelsa* which have been seen in Uganda are those in Bwamba Forest, especially in one group near the edge of the forest at the base of Mt. Ruwenzori, close to the locality where *C. canephora* is abundant. This group of *C. excelsa* consists of a few trees, but they are large ones; the trunks are up to 9 in. in diameter, slightly buttressed at the base and unbranched at a height of 15 ft.; the total height of the trees is about 40 ft. The leaves are large, over 12 in. long and 6 in. wide, with the veins deeply indented; the fruits are scarlet and rectangular in profile.

A similar type of *C. excelsa* also occurs in the Itwara Forest, growing near the western edge in association with *C. canephora*. The leaves are very large, like those of the *C. excelsa* in the Bwamba Forest, but none of the trees seen has been more than about 20 ft. high, although it is said that there are bigger ones in the eastern side of the forest.

The Zoka Forest contains some specimens of *C. excelsa* very different from those of the Bwamba Forest: the trees are smaller, more spreading, and have much smaller, flatter leaves. These differences may be attributed to the differences in habitat, for the Zoka Forest trees are growing in a drier climate and with less overhead shade than are the trees in the Bwamba Forest. But there is no doubt that the differences are also partly due to genetical factors, for the distinctive leaf-characters are well exhibited by young plants from the two localities which are growing close together on the Kawanda Experiment Station—the Bwamba Forest type has the large leaves with indented veins and the Zoka

Forest type has smaller, flatter, leaves (Plate 2, fig. 4). As in the other forests, so also in the Zoka Forest, *C. excelsa* grows in association with *C. canephora*; some of the ground on which it is growing in the Zoka Forest is inundated in the wet seasons.

C. excelsa was also found in 1941 near Killak, to the east of the Zoka Forest, in a strip of riverain forest similar to the Zoka, with *Khaya grandifoliola* as a characteristic tree. The type of *C. excelsa* seemed to be very like that of the Zoka Forest; no *C. canephora* was found in this locality.

The differences between the large-leaved and the small-leaved types of *C. excelsa* are so striking that they might almost be regarded as separate species: in fact, some specimens from Uganda have been determined as *C. liberica*. But, as in the case of *C. canephora*, it must be recognized that there can be great variation inside the species: in the Zoka Forest there are great differences between individual trees of *C. excelsa*, even in the character of the fruits, some of them being rectangular, with a small eye, as is typical for *C. excelsa*, whilst others had a larger eye and were more cylindrical like the fruits of *C. liberica*. When the two species, *C. excelsa* and *C. liberica*, are grown in proximity, they intercross so freely that it seems possible that they may be extreme forms of one species. Chevalier [3] has pointed out that in both species there are many eco-types which have been dignified with specific names and Porteres [4] has discussed the variability among the wild population of *C. excelsa* in the Ivory Coast.

C. excelsa grows wild on a wide range of soils in Uganda—in the Bwamba Forest on an alkaline grey clay, in the Itwara Forest on an acid red clay loam, in the Zoka Forest on neutral grey sandy loam, and at Killak on slightly acid, brown sandy loam. The species, which is a typically West African one, appears to reach the eastern limit of its growth in the wild state at Killak, for it is common in the countries to the west and north-west of Uganda, and has also been reported from the Anglo-Egyptian Sudan, but only from forests on the west bank of the Nile.

Coffea spathicalyx

C. spathicalyx appears to be the most uncommon species of wild coffee in Uganda, for it has been found only in two restricted localities—in the Bwamba Forest and in the Zoka Forest; if it were abundant in any other forest, it is not likely to have been overlooked, as it is easily recognized by its habit and by the shape of its leaves.

There is a small group of *C. spathicalyx* near Sempaya in Bwamba, just above the swamp containing wild oil-palms, and close to the wild trees of *C. canephora* and *C. excelsa*. The *C. spathicalyx* has grown into small erect trees, up to 15 ft. in height, with smooth trunks up to 3 or 4 in. in diameter, bare for the bottom 5 or 6 ft.; above that height are sparse, spreading primary branches. The leaves are dark green and resemble those of *C. arabica*, but have a long attenuated 'drip tip' and are about 4 in. long and 1½ in. wide. The flowers have a characteristic spathe-like calyx and a corolla which resembles that of *C. arabica*.

The root-system seems to be less superficial than that of other wild coffees in Uganda, having a very strong tap-root and comparatively few spreading lateral roots: the seedlings also differ from those of other coffees in that the cotyledons are cordate and not orbicular, as in other species.

The other locality where *C. spathicalyx* has been found in Uganda is in the north-eastern part of the Zoka Forest, at some distance from the parts where *C. canephora* and *C. excelsa* are growing. These two species of coffee are growing on mixed forest, with an uneven canopy, near the rivers; but *C. spathicalyx* grows on a part away from the river, where the tree-layer is composed of a pure stand of a species of *Strychnos* which forms an even canopy at a height of about 60 ft. It seems probable that this type of forest represents the climax forest; the undergrowth is much less dense than that in the mixed forest; *Argyromuellera macrophylla* is dominant, *Whitefieldia elongata* and *Capparis afzelli* are common.

In some parts of this *Strychnos* forest *C. spathicalyx* is locally dominant, forming groups of small trees with smooth stems about 3 in. in diameter, bare to a height of about 12 ft., and crowned with spreading primary branches; the total height of the trees is nearly 20 ft. As in the case of the Bwamba forests, the dull dark green colour of the leaves and their long drip tips are very noticeable (Plate 3, fig. 5). Both in the Bwamba Forest and in the Zoka Forest, and also in the Laboni Forest, just over the border of the Anglo-Egyptian Sudan, where it occurs in association with *C. canephora*, *C. spathicalyx* is growing on soil which is neutral or slightly alkaline.

Discussion

The genus Coffea is represented by one or more species in most tropical African countries. Uganda, situated near the centre of the continent, is the meeting place of the West African and East African floral zones. It is not surprising, therefore, that there should be growing in the Protectorate the typically West African *C. excelsa* and *C. canephora*, together with the East African *C. eugenioides*; other smaller species, such as *C. swynnertonii*, *C. ligustroides*, and *C. zanguebariae*, which are to be found to the south and south-east of Uganda, have not been found in this country.

The fact that *C. canephora* is indigenous to the country where it is a major crop, greatly assists selection work on the species. Strains of wild *C. canephora* from the various forests in Uganda and in the south of the Anglo-Egyptian Sudan are in cultivation at the Kawanda Experiment Station and in the Botanic Gardens, Entebbe; at Kawanda they are growing in full sun, on a slope facing west, and at Entebbe they are in shade, on a slope facing east. The behaviour of these strains under cultivation has shown many interesting differences between them, of which one of the most striking is that of the degree to which they can tolerate exposure to full light and heat of the sun. The narrow-leaved strains, such as those from the Kibale and the Laboni forests, stand exposure well; but the broad-leaved type from the Itwara Forest suffers greatly, many leaves being ill formed and contorted at the edges.

These wild coffees give good crops under cultivation but, on the whole, the size of the beans they produce has been disappointing: trees in the forest, whose beans were very bold, have been selected, but their progeny in cultivation have given much smaller beans. As a source of breeding material from which to achieve quick results, the wild *C. canephora* trees in the forests have not been so useful as the trees growing on native farms; these trees have been derived from the forests at first or second hand, and a process of selection has resulted in the retention only of forms which will flourish under cultivation. It is noteworthy that the large old trees on native farms are of the types with rather small, narrow leaves; few of the broader-leaved types have persisted under the conditions of peasant cultivation, although one strain derived from the Itwara Forest coffee has produced large crops and bold beans under plantation conditions.

Apart from their value to selection work, the wild populations of *C. canephora* have afforded most valuable material for study of the environmental requirements of the species. Firstly, the fact that this plant always grows in shady conditions in the wild state indicates that it is a shade-lover; the presence of a canopy, even a broken canopy, of trees has enabled the coffee to persist in areas, such as the north of Uganda, where it would soon die if unshaded.

Secondly, the fact that *C. canephora* grows often in swampy hollows is an indication that it has a superficial root-system, a fact which is demonstrated by the figures of the vertical distribution of the roots in the soil, quoted above. If the root-system is so very shallow, it is obvious that cultivation should be reduced to the minimum consistent with weed-control; restriction of cultivation has been practised on the Kawanda Experiment Station with the result that, in spite of conditions of soil and climate that are far from ideal, excellent vegetative growth and excellent cropping have been achieved.

Thirdly, the fact that *C. canephora* is seldom found in the wild state on acid soils gives an indication of the preference of the plant for neutral or alkaline soils; and the fact that even when the soils of the habitats are poor in lime and acid in reaction, as in the Itwara Forest, yet they are well supplied with potassium, indicates that the potassium status of the soil is important. This hypothesis is supported by the beneficial effects on the growth and appearance of *C. canephora*, which are often seen to follow a dressing of wood ashes, especially if the coffee is growing on a poor soil.

C. arabica L., the most important species of coffee in commerce, has not been found wild in Uganda; it does not seem to be indigenous to the country nor has it been noticed as an escape from cultivation, although it had been cultivated for more than forty years and has been planted in close proximity to some forests. Yet, on the Boma Plateau, in the south-east of the Anglo-Egyptian Sudan, *C. arabica* grows wild in forests lying at altitudes between 4,000 and 5,000 ft. and containing many of the same species that are abundant in the undergrowth of Uganda forests at similar elevations [6]. The absence of this coffee in the wild state in Uganda may be due to the fact that the strains in

cultivation are not suited to such low altitudes, or to the fact that the soils are not ideally suited to the crop.

Three wild species of Coffea in Uganda—*C. eugenioides*, *C. canephora*, and *C. excelsa*—are all diploid, having 22 chromosomes. *C. arabica* is tetraploid and has 44 chromosomes. Krug and Mendes [7] have suggested that *C. arabica* may be an autotetraploid; it is possible that it may have arisen from *C. eugenioides*, a diploid species which resembles it in miniature, and cytological work on the genus Coffea should produce valuable information on this and other points relating to the breeding of coffee. Interspecific crosses have been produced between the various forms that were grown on the Kampala Plantation, and they have occurred naturally; but no wild hybrids have been noticed. (It was thought that the small-leaved *C. excelsa* from the Zoka Forest might be a hybrid between that species and *C. canephora*, but the plant is so fertile that it is unlikely to be of hybrid origin.) Up to the present time no interspecific crosses have been found that are of much use for commercial coffee-growing, as their yields are poor; crossing and selection inside the species appear to be the methods of most use in coffee-breeding. In order that such work can be carried out to the fullest advantage, it is highly desirable to study the wild populations of the plants.

REFERENCES

1. M. T. Dawe, Report on a Botanical Mission through the Forest Districts of Buddu and the Western and Nile Provinces of the Uganda Protectorate. London, 1905.
2. W. J. Eggeling, The Indigenous Trees of the Uganda Protectorate. Entebbe, Uganda, 1940.
3. A. Chevalier, Les Caféiers du Globe. Paris, 1929.
4. R. Porteres, Étude sur les Caféiers spontanés de la section 'Des Eucoffeae': leur répartition, leur habitat, leur mise en culture et leur sélection en Côte d'Ivoire. Annales Agricoles de l'Afrique Occidentale, 1937, **1**, 68–91.
5. T. F. Chipp, The Imatong Mountains, Sudan. Kew Bull., 1929, 177–97.
6. A. S. Thomas, The Wild Arabica Coffee on the Boma Plateau, Anglo-Egyptian Sudan. Empire J. Expt. Agric., 1942, **10**, 207–12.
7. C. A. Krug and A. J. T. Mendes, Cytological Observations on Coffea. IV. J. Genet., 1940, **39**, 189.

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FIG. 1. *Coffea eugenioides.* A large specimen in the Kangavwe Forest.

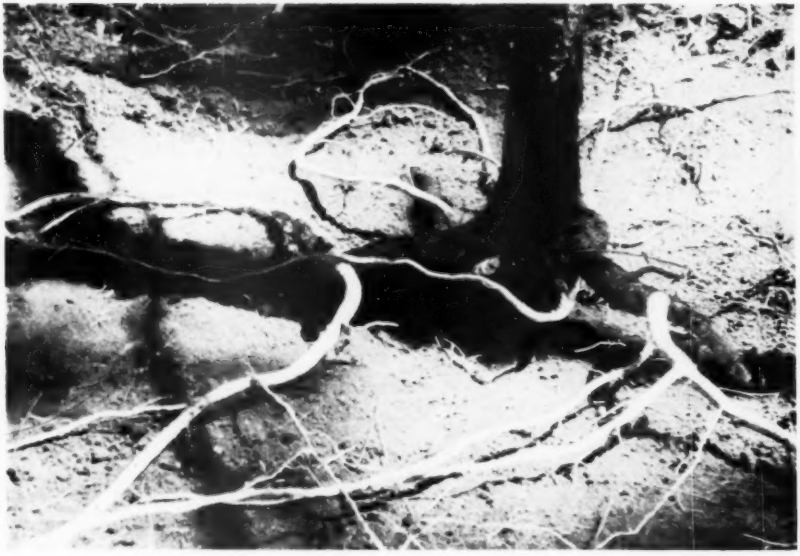

FIG. 2. *Coffea canephora,* Kibale Forest. The thin layer of fallen leaves and mould has been scraped away, exposing the lateral roots which radiate near the surface of the ground.

FIG. 3. *Coffea canephora*, Bwamba Forest. Primary branches from adjacent trees, growing under the same intensity of light but showing differences in size and shape.

FIG. 4. *Coffea excelsa*. Primary branches of plants on the Kawanda Experimental Station; on the left the broad-leaved type from the Bwamba Forest; on the right the narrow-leaved type of the Zoka Forest.

FIG. 5. *Coffea spathicalyx* in the Zoka Forest showing the drip tips of the leaves.

FIG. 6. Barbuk area (Anglo-Egyptian Sudan). Root-system of wild *Arabica* coffee growing in the forest. (*Cf.* this J., 1942, **10**, 207–12.)

FIG. 7. Barbuk area (Anglo-Egyptian Sudan). Leaves of wild *Arabica* coffee growing in the forest. (*Cf.* this J., 1942, **10**, 207–12.)

THE YIELD AND MATURITY PERIOD OF POTATOES (*SOLANUM TUBEROSUM*) AT LOW LATITUDES

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VERY definite opinions have been expressed that the potatoes of commerce are long-day plants. For example, Bald [1] writes that commercial potatoes 'produce a full crop. . . where they receive more than 13 hours full daylight each day. Many will produce . . . 50 to 75 per cent. yield under short-day conditions, but never their maximum crop.' Even more emphatic statements have been made by Driver [2]: 'It has always been difficult, if not impossible, to grow potatoes in tropical countries. This is due to the fact that potatoes have been bred for and become adapted to the light conditions of the temperate regions and form tubers only when the daylight period reaches a certain minimum. In tropical regions the daylight period does not exceed twelve hours, and this is insufficient to initiate tuber development.' Because short day-length is one invincible circumstance of tropical agriculture, and because the question is fundamental to a policy of potato selection for the tropics, the evidence for such statements as the foregoing needs close examination. It is of course obvious at the outset to anyone who is aware of the East African potato-growing industry that the last part of Driver's statement is not applicable to that country.

The history of the European potato stock is relevant in this connexion. On one view, held especially by Russian botanists [3], our potatoes derive predominantly from plants native in Chile at about 45° S., where the summer daylight lasts up to 15½ hours. If this is correct, then in their ancestry as well as in their adaptations to North-west Europe, the varieties that have been used for so much of the tropical potato-planting are long-day plants. The other view, now endorsed by Salaman [4], is that the source of the European potato introductions, not only the original ones, but also the 1851 infusion of 'Rough Purple Chili', was the Andean dispersal centre, where presumably they were adapted to short days. If they are now thorough-going long-day plants it must be posited that short-day adaptation has been among the characters that have been 'selected out' during their European sojourn. But the question naturally arises whether the selection has been complete enough to make the presumed short-day adaptation impossible to recover.

Experimental Evidence

What is the experimental evidence for the 25–50 per cent. reduction in yield stated by Bald to be a consequence of the short day? Much of the work on the photoperiodism of the potato proves, on critical examination, to be not strictly relevant to, or not entirely conclusive for, our present purposes. Some experiments were complicated by the unnaturally high temperatures to which the plants were subjected; in fact

in hardly any of them do mean temperatures seem to have been within the range 59–64° F., those which by consensus of opinion are the best [5]. Moreover, in considering any experiments that involve artificial light, the possibility must be borne in mind that the physiological effects may not be the same as with natural light: just as the effect of tropical daylight on the plants may be different from that of higher-latitude daylight. Again, constant day-length, which is a feature of most experiments as well as of Nature in the tropics, may have effects different from those of the procession of the seasons in higher latitudes [6].

Some of the potato experiments have measured rate of tuber-formation rather than yield, because the plants were dug before all of them were mature. Garner and Allard [7] concluded their experiment at 99 days, when the plants receiving 13 and more hours of daylight were still green but those receiving 5 and 10 hours respectively were 'dead'. This, the first experimental demonstration that maturity period can be reduced by shortening the day, has been repeatedly confirmed by subsequent workers, but only incidentally; and it does not appear that the nature of the correlation between maturity and light-period has been examined experimentally in detail. Moreover, Beaumont and Weaver [8] produced evidence, which does not seem to have been confirmed or followed up, that maturity period can be shortened by reducing the light-ration only at comparatively high temperatures. Their results with potatoes kept at between 50° and 60° F. were contrary to those with others subjected to 60°–75° F. Garner and Allard concluded that maximum yield took place under a 13-hour day and found 'relatively intense tuber-formation' in their 10-hour plants: but the yield from their 15-hour plants, still green when dug, might have surpassed the others eventually, a point not mentioned by Arthur *et al.* [9] in their review. For similar reasons the experiments of McClelland [10] in Puerto Rico (18° N.) are also inconclusive for our purpose.

Tincker [11] got more tubers on King Edward under a 12-hour day than with either shorter or longer days, but Sharpe's Express gave the best yield under long days (April 22–July 31). Apart from its conflicting results this experiment is marred by the fact that the material seems to have been neither ample nor healthy.

Other results, purporting to be more conclusive than the foregoing, are unfortunately in conflict. On the one hand:

(*a*) Beaumont and Weaver [8], experimenting with Katahdin at mean temperatures of (*a*) 55° F., (*b*) 67° F., and natural (progressive) day-lengths from 9½ hours upwards and fixed day-lengths of 12, 15, and 18 hours, found 'from the standpoint of yield and early maturity . . . the 15-hour light exposure in the cool greenhouse the most satisfactory'. At about 67° they still got slightly the best yields with 15 hours light, but not, it appears, significantly more than with 12 hours.

(*b*) Werner [12], after experimenting with two strains of Triumph given 11- and 16-hour days at 62°–65° F., reported that in the long-day plants: (i) Growth continued for several weeks longer and tubers were produced several weeks later; (ii) 'Total tuber-weight was about the same [under both light-periods] by the time maximum weight was

attained by 11-hour plants, after which tuber-production continued to increase with 16-hour plants till finally it was approximately twice as great.'

If, as appears from a study of Werner's paper, the data plotted in his Fig. 5 are the basis for this last conclusion, then they do not form a satisfactory one. It seems to be obtained by comparing the tuber-weights obtained on the last digging (at 125 days) in each series, when, according to the figure, in Strain 12 the ratio of short-day to long-day weights was 33:78, in Strain 23, 31:50. The data for successive diggings of short-day plants present, however, the curious feature that from the 86th day onwards there was a progressive diminution, eventually exceeding one third in weight of tubers obtained. No explanation of this anomaly is offered. Some error in technique may be suspected: and the statement that 'tuber production was approximately twice as great' in the long-day plants does not seem justified. There is, in any case, nothing to show that the initial variability of the planting material was tested; the number of plants compared at each digging does not exceed 4; and the significance of the results is correspondingly doubtful.

(*c*) Miller and McGoldrick [13] are cited as finding that 'under field and controlled conditions plantings of potato under short-day conditions . . . had more regular-shaped tubers than potatoes under long-day. The long-day plants had, however, a higher yield.' Unfortunately, no figures are given in the abstract and the original is not available for study. Contrary to the above findings:

(*d*) Doroshenko *et al.* [14] reported that in experiments with a series of potato varieties a 12-hour day gave a higher yield than the long day of the Leningrad summer. Like other workers they found the ratio of weight of tubers to weight of tops greater with the shorter day.

(*e*) The conclusions of Arthur *et al.* [9] might be taken as supporting Doroshenko's, for the yields (not specified) were described as only 'fair' from both control plants and plants receiving an extra 6 hours artificial light a day. Their conclusions must, however, in any case be interpreted with caution. In their summary they state 'tuber production was found to be favoured by low temperature [68° F.] in combination with high light intensity and long days. . . . This variety [Irish Cobbler] formed many large tubers when grown with continuous illumination.' This, so stated, without qualification, is misleading. The footnote to their Table 16 shows that all 24-hour-day plants received extra carbon dioxide. Moreover, 68° F. is, for the potato, not 'low', but above the optimum.

(*f*) Werner [5] reported maximum tuberization with moderate temperature and day-length, actually 60°–64° F. and 10–13 hours. But it is to be feared that comparison is vitiated by the temperatures to which the plants were exposed in his other four treatments. In one the means varied between 62° and 70° F., in the other three from 72° F. upwards—temperatures so high as probably to connote maxima actually deleterious.

Field Data

The relation of day-length to yield cannot properly be considered apart from the variation in the maturity period because this affects so

greatly the total amount of light received by the plant while it is physiologically active. Maturity is a stage that is judged subjectively, and dying of the tops due to disease, e.g. Early Blight [18], may confuse or hasten the judgement that the potatoes are mature. Moreover, it has been shown [15] how in different localities within the United Kingdom and in different years the maturity period may in a single variety vary by 16 per cent. of its mean. Nevertheless, the maturity periods of potatoes in all the low-latitude areas for which information is available are so strikingly less than in the United Kingdom as to leave no doubt that the reduction is real: and a large measure of reduction is so widely distributed that the early appearance of maturity cannot all be due to disease. The best-documented data are brought together in Table 1. It will be noted that there is no evidence of correlation between latitude and degree of reduction.

TABLE 1. *Maturity Periods of Potatoes in Different Latitudes*

Area	*Latitude*	*Type of variety*	*Approx. maturity period (days)*		
			In U.K.	*In locality named*	*Per cent. reduction*
East Africa (unpubl. data)	2° N.–5° S.	Late	175	120	32
		Early main-crop	140	96	31
Java [16]	6°–8° S.	Main-crop	150	105	30
Fiji [17]	18° S.	Late	175	80	54
Southern Rhodesia [18]	*c.* 19° S.	Late	175	125	28
Hawaii [19]	20° S.	Second early	135	80	40
South Africa [20]	23°–35° S.	Earlies	130	90	31
		Late	160	120	25

Bald [1] remarks that 'environmental conditions sometimes appear to act in an indefinite and generalized way, causing local variations of the varietal type. A recent example is the Katahdin, which in the few years it has been established in the Tableland areas of New South Wales, appears to have developed an earlier maturity and possibly a lower yield.' But the N.S.W. latitude is at least 10° lower than that in which Katahdin does so well in the U.S.A. It may be suspected, therefore, that the reduction in maturity period observed in N.S.W. is a direct reaction of the individual plant to the reduced light.

Because the end of the maturity period is judged largely by the withering of the haulm it is clear that the period during which the plant is actively photo-synthesizing will tend to be shorter than, rather than coincident with, the maturity period; but for the present purpose the difference may perhaps be taken as common to all areas and ignored. The hours of daylight to which plants are subjected during their growing periods in various countries are given in Table 2. Each total, in col. 9, is regarded as the respective 'light-ration', and that of the Scot-

tish Lowlands, *c.* 55° N., the home of so many varieties, as the standard. Since we know nothing of the intensity thresholds for photo-synthesis of *S. tuberosum*, all periods are sunrise to sunset, the longer twilights of high latitudes being ignored.

TABLE 2. *Daylight Hours in Various Countries*

Area	*Degrees from Equator (mean)* (2)	*Maturity type* (3)	*Planting season* (4)	*Maturity period* (5)	*Max.* (6)	*Min.* (7)	*Mean* (8)	*Light-ration (hours)* (9)
Scottish Lowlands	55	Earlies	Summer (planting Apl. 15)	130	17·4	14·0	16·2	2,110
		Late		175	17·4	11·2	14·8	2,610
South Africa	29	Earlies	Summer	90	14·0	13·4	13·7	1,240
		Late		120	14·0	13·0	13·6	1,630
		Late	Winter	120	11·5	10·5	11·0	1,320
Hawaii	20	2nd early	Jan.–Mar.	80	12·1	11·0	11·5	920
S. Rhodesia	19	Late	(1) Summer	125	13·3	12·7	13·0	1,625
			(2) Winter	125	11·9	11·0	11·5	1,440
Fiji	18	Late	Winter	75	11·4	11·1	11·2	8
S. Tanganyika	9	Late	(1) Sept.	120	12·6	12·1	12·4	1,490
			(2) Feb.	120	12·4	11·6	12·0	1,440
Java	7	Main crop	Not stated: if					
			(1) Winter	105	11·9	11·7	11·8	1,240
			(2) Summer	105	12·5	12·4	12·5	1,310
Kenya	0	(1) Late (2) Early	Both 'rains'	120	12·1	12·1	12·1	1,450
		main crop	,, ,,	96	12·1	12·1	12·1	1,160

The differences in light-ration disclosed by Table 2 are startlingly high. It shows, for example, that Kerr's Pink in Kenya produces its crop on little more than half its U.K. light-ration. The table provides no evidence of a direct correlation between mean day-length and maturity period. Other factors are presumably contributing to cause the big differences in the latter. The apparent close correlation (within any one maturity type) between maturity period and light-ration is doubtless because in the calculation of the latter the maturity period is one of the factors.

It is instructive to consider some of the yields at low latitudes in conjunction with the light-ration. For this purpose average yields for countries are useless. Almost everywhere outside the North Temperate region they seem excessively low, e.g. 1½ tons per acre in South Africa [20], 2½ in Northern Rhodesia [21], 2·6 tons in Australia [1], compared with 6 tons for U.K. as a whole, 8 for Lincolnshire, Holland, and Belgium [22]. But almost all factors, and not least those under human control, are against a good yield in the low-latitude countries. In local literature heat, drought (a special enemy in Australia), uncontrolled diseases, seed bad in every way, poor cultivation, utterly inadequate manuring, often originally infertile soil, even premature digging to forestall predial larceny, are all admitted to be factors militating against good yields. Some of these factors are clearly no less prevalent in the potato cultivation by the local Europeans than by 'native' cultivation. Hence if short-day does depress yield it is only one of so many inimical factors operating at low latitudes that from field evidence its importance cannot

be assessed and indeed its influence cannot irrefragably be established at all. In Australasia itself, where the depressent effect of short-day has recently been rated so high, a halt in this line of thought might have been called by the fact that whereas the average yields for West Australia and South Australia are 4·45 and 3·83 tons they are still lower for Tasmania [1], which lies farther from the Equator, at 41–44° S., and actually in the same latitude as Chiloé, the potato's hypothetical long-day home.

Though the general low-latitude averages, depressed by 'marginal' conditions of all kinds, are of no significance for the present discussion, the high yields that have been recorded from time to time emphatically are. They show what the potato is capable of in the field on greatly reduced light-rations when its other conditions are good.

The well-documented data from Southern Rhodesia are of special significance in this connexion: whilst the average for the colony is actually no better than 1·4 tons to the acre, good commercial growers, with a high standard of cultivation and manuring, obtain 6·7–7·8 tons, exceptionally up to 13·4 [23] or even more; and 3 acres under the Department of Agriculture yielded 12·5 tons per acre [24].

Some of the high yields recorded at low latitudes are given in Table 3. Those yields obtained on a commercial scale are marked C; the others are from plot experiments.[1]

TABLE 3

Area and reference	*Variety and type*	*Yield attained: tons per acre*	*Percentage reduction in light-ration (hours)*
South Africa [25]	Up-to-date (late)	10 C (irrigated: winter)	49
S. Rhodesia [23]	" " "	6·7–13·4 C 12·5 C	38
Tanganyika [26]	Kerr's Pink (late)	6·0	44
Kenya [27]	Majestic (early main crop)	6·8	44
" [28]	Majestic (late)	8·0 C	44
Hawaii [19]	British Queen (2nd early)	6·0	56
Fiji [17]	Up-to-date (late)	7·0	65

Discussion

A review of the physiological work shows that information on the effect of light on the tuber-yield of the potato plant is inadequate and conflicting. There is need of experiments, especially on British varieties, carefully planned to ascertain the photo-synthetic relations of potato plants to light of all intensities up to tropical sunlight; to ascertain the effect of different day-lengths, fixed and variable, on yield; and to ascertain how these effects are modified by temperature. Meanwhile, the existing experimental data do not appear to warrant the sweeping

[1] Col. 4 shows the percentage, as calculated from col. 9 of Table 2, by which the light-ration (hours) received by the crop in each low-latitude locality is less than the hours the same variety would get in the Scottish Lowlands.

assertions that have been made about the depressing effect of short day on yield.

Experimental evidence and field observations agree in demonstrating that the maturity period of potatoes is greatly reduced by short days. At low latitudes the result is that during their growing periods potato plants receive only half to two-thirds as many hours of daylight as plants of the same variety receive in the Scottish Lowlands. Even so, when the care taken by tropical growers approximates to that regarded in European countries as the crop's due, yields that are, by any standards, excellent, are undoubtedly obtained and are a commercial success. It is certain, therefore, that the short days of low latitudes are not an overriding factor in the low yields prevalent in the tropics. It is possible that experiment will confirm that shortened periods of daylight depress yield but will disclose some countervailing influence in the tropics. For example, in Kenya 'the actinic properties of the 12-hour day are greatly in excess of the 18 hours at higher latitudes' [29].

On an impartial view of all the evidence it is not clear that the excessively low average yields of potatoes obtained in practically all low-latitude countries are due in any important degree to the prevailing short days.

Acknowledgements

Many of the field data on which this discussion is based are unpublished, but have been communicated by departments and individuals specified in the list of references. I must thank also those who have read this paper critically, especially my colleagues L. R. Doughty and J. Glover. Tables giving the duration of daylight at various latitudes were provided by the British East African Meteorological Service.

REFERENCES

1. J. G. Bald, Austr. Counc. Sci. Ind. Res. 1941. Pamph. No. 106.
2. C. M. Driver, N.Z. J. Sci. Tech. A, 1941, **33** (3A), 180A–184A.
3. Anon, Imp. Bur. Plant Genet. Cambridge, 1936.
4. R. N. Salaman, Indian J. Agric. Sci., 1938, **8,** 119–29.
5. H. O. Werner, Univ. Nebraska Agric. Expt. Stat., 1934, Res. Bull. No. 75.
6. V. Razumov, Bull. Appl. Bot. Genet. Plant Breed., 1931, **27** (5), 1–46.
7. W. W. Garner and H. A. Allard, J. Agric. Res., 1923, **23,** 871–919.
8. J. H. Beaumont and J. G. Weaver, J. Amer. Hort. Soc., 1931, **28,** 285–90.
9. J. M. Arthur, J. D. Guthrie, J. M. Newell, Amer. J. Bot., 1930, **17** (5), 416–82.
10. T. B. McClelland, J. Agric. Res., 1928, **37,** 603–28.
11. M. A. H. Tincker, Ann. Bot., 1925, **39,** 721–54.
12. H. O. Werner, J. Agric. Res., 1940, **61,** 761–90.
13. J. C. Miller and F. McGoldrick, Amer. Potato J., 1941, **18,** 261–5, cit. Hort. Abst. **11,** 1221.
14. A. V. Doroshenko, E. D. Karpechenko, and E. I. Nestorova, Bull. Appl. Bot. Genet. Plant. Breed., 1930, **23** (2), 31–60.
15. R. N. Salaman, Potato Varieties. Cambridge, 1926.
16. E. Paravicini, Die Kartoffelkultur in Niederländisch-Ostindien. Tropenpflz., 1923, **26,** 75–80, 123–6.
17. C. Harvey, Potato Variety Trials. Agric. J. Fiji, 1941, **12,** 80–1.
18. S. D. Timson, Rhod. Agric. J., 1942, **39,** 274–95.
19. Report of the Hawaii Agricultural Experiment Station, 1938.

20. H. D. LEPPAN and G. J. BOSMAN, Field Crops in South Africa. Jo'burg., 1923.
21. Department of Agriculture, Northern Rhodesia. Unpublished data.
22. J. C. WALLACE, Potatoes. Min. Agric. Fish. England, 1941, Bull. No. 94.
23. S. D. TIMSON, The Potato. Rhod. Agric. J., 1931, **28**, 716–21, 837–45, 929–36, 1008–19.
24. J. C. HOPKINS, Department of Agriculture, Southern Rhodesia. Unpublished data.
25. Department of Agriculture, Union of South Africa. Unpublished data.
26. Department of Agriculture, Tanganyika. Unpublished data.
27. Department of Agriculture, Kenya. Unpublished data.
28. J. K. HILL, Sabukia, Kenya, Personal communication.
29. A. WALTER, British East African Meteorological Service. Personal communication.

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FOR a fuller discussion of the literature on this subject the reader is referred to a bulletin in the press prepared by the Imperial Bureau of Plant Breeding and Genetics, Cambridge, and entitled 'Photoperiodism in the Potato'. Here the problem is discussed from all angles, the effect of photoperiodism upon vegetative growth, flowering, tuber-formation, maturity, &c., as well as the relation between photoperiodism and temperature. The same general conclusion is reached that contrary to the opinion expressed in literature over the past few years, the short day of the tropics is not the sole determining factor in the low yields so frequently obtained there. Factors of temperature, drought, diseases, infertile soil, and poor cultivation are probably of more importance. Except when short days restrict the vegetative growth below that needed to synthesize sufficient food for tuber storage, they would seem to encourage more efficient tuberization than long days. Probably the best conditions for high tuber-yields are those found in the main potato-growing regions of temperate latitudes—long days to encourage vegetative growth followed by short days to turn the plant activity towards efficient tuberization, with a temperature throughout the growing season of round 60° to 65° F. Experiments have failed to show that our so-called long-day varieties will not yield well under short days provided that the temperature is round the optimum and growing conditions are good, but there is need for extensive controlled experiments in tropical countries on the photoperiodic reaction of the potato. Dr. J. G. Hawkes of the Imperial Bureau of Plant Breeding and Genetics, who made collections of potatoes in South America, has said (personal communication) that the view is held in the Andes regions that the varieties of *S. tuberosum* from Europe and North America do not thrive so well there as the native varieties and species. However, he was unable to find evidence of any detailed experiments with northern varieties, so that proof is lacking in support of the view. It is possible that some factor other than day-length, such as greater susceptibility to disease or use of inferior seed, may have been responsible for the poorer yield.

The inhibiting effect of long-day upon tuber-formation in some of the South American species has, on the other hand, been established beyond all question. Examples are found in some strains of *S. Juzepzukii*, which never form tubers naturally in higher latitudes but yield well when the day-length is artificially curtailed.—*Edit.*

GRASS COVERS IN THEIR RELATION TO SOIL STRUCTURE

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With PLATE 5

Introduction.—In Uganda the decade 1924–34 saw a vast amount of experimental work on the maintenance of soil fertility by rotation of crops and by manuring. The rotations used included one or more green-manure crops. In general, it may be said that farmyard manure did increase yields, particularly of food crops, but only at comparatively heavy rates of application. Green manures were unsuccessful, although there was some evidence that when dug in at least 6 weeks before sowing the main crop, they did increase yields slightly; the key to the situation seemed to be the availability of moisture during the rotting period; only when rainfall was plentiful during this time did the green manure rot well and benefit the subsequent crop. Usually the optimum periods for the growth and incorporation of green-manure crops coincide exactly with the peasant farmers' busiest times on food crops, and as increased yields are not even then assured, it is difficult to visualize any future for a general green-manuring programme. On the chemical side analyses of a large number of soil samples, drawn from the normal field experiments, failed to reveal any correlation between the normal food elements of the soil and the yield of crops. The inference is that under local conditions the nutrient status of the soil is not a major factor in determining yields.

Parallel with these field experiments observations were being made on the effects of an elephant-grass cover on soil structure. The most striking evidence was found in 1928 when two pits, 20 yds. apart, were dug in the same kind of soil. One was in a coffee estate which had been clean-cultivated for 10 years, the other was in a good stand of elephant grass just outside the estate boundary. The top-soil of the former was a grey powdery sandy loam, only 6 in. deep, with few roots in the surface-layer and none at all in the subsoil. Under the grass cover the top-soil was a grey-black loam of excellent structure, 15–18 in. deep, full of roots some of which had penetrated 6 ft. into the subsoil. With the clue thus provided observations were extended to other grasses; legumes were studied at the same time. Grasses appeared to be much more effective than legumes in structure formation (Plate 5). In soils of good structure plant-roots were deeper and more widespread, and were clearly drawing on a much greater volume of soil for moisture and nourishment than those in soil almost completely broken down by continuous cultivation. As a result of these and similar long-continued observations the grass rotation was adopted on all the Government experimental farms in 1933–4. Under elephant grass 3 years' rest followed 3 years of cultivation. In the short-grass areas 4 years of rest were allowed after 2 years of cultivation. These rotations represent an acceleration of the old native methods of shifting cultivation.

Early Experiments

This complete change of policy brought a new impetus and direction to field experiments. Plots were established at the main centres for studying both indigenous and exotic grasses; ease of establishment, drought-resistance, root-range, and palatability were considered in addition to crumb formation.

At both Kampala and Serere between 30 and 40 grasses were established in plots of about 1/40th acre and, later, some grasses in pure stand and grass mixtures were studied. Three years after the establishment of the covers the soil profile developed under each was exposed. Some of these are illustrated in Plate 5.

Although the adoption of the grass rotation may be regarded as an event of the greatest importance in the agricultural history of the country, both for maintenance of soil fertility and soil conservation, there remained many problems which depended for their solution upon a reasonably rapid and reliable method for the assessment of soil structure. In the first instance, it was necessary to find out the relative effects of various grasses on the crumb structure of each major soil type. After having chosen the grass or grass mixture most suitable for resting cover, the optimum period of rest for the regeneration of crumb structure and the best cultivation period had to be fixed, bearing in mind the population density and the main food crops in each area.

Experimental

The first method of assessing soil structure tried was based on pore-space calculation from the usual determinations of apparent and real specific gravity. Five samples per plot, taken with a tube of the Veihmeyer [1] type, were examined, but it was found that the variation within treatments quite outweighed the differences between treatments. This variation was not due entirely to soil heterogeneity; stones and roots caused difficulty in some cases, and always there was doubt whether the whole of the core had been taken when the implement was withdrawn. The older metal-box method gave more concordant results. The boxes used were of sheet iron with snug-fitting ends. Their volume, which was obtained both by measurement and by filling with water from a measuring cylinder, was nearly 2 litres. Results by this method obtained from some of the grass plots at Kampala and at Serere are given in Tables 1 and 2.

TABLE 1. *Kampala Grass Plots. % Pore Space under Different Covers 3 years after Establishment*

Cover	*Pore space %*	*Cover*	*Pore space %*
Brachiaria decumbens	52·9	*Rhynchelytrum repens*	46·1
Cynodon plectostachyon, var. *A*	52·1	*Brachiaria orizantha*	45·7
Cynodon plectostachyon, var. *B*	51·6	*Melinus maitlandii*	45·1
Panicum maximum	50·0	*Sporobolus pyramidalis*	44·3
Paspalum notatum	49·4	*Brachiaria soluta*	43·5
Setaria sphacelata	47·5	*Chloris gayana*	41·8
Hyparrhenia rufa	47·0		

TABLE 2. *Serere Grass Plots*

Cover	*Pore space %*
Panicum maximum	57·7
Cynodon plectostachyon	53·3
Brachiaria decumbens	47·4
Paspalum notatum	46·1
Hyparrhenia rufa	42·7
Rhynchelytrum repens	41·5

It is noteworthy that the same grasses head the list on each soil type although not exactly in the same order. However, too much weight must not be attached to these figures as the plots were not replicated, but it is quite safe to say that grasses vary considerably in their power to regenerate structure. This method was clumsy, time-consuming, and inefficient for the work it was required to do. The Keen-Raczkowski [2] box method was then tried on samples taken from an elephant-grass rotation at Bukalasa. Three spade samples from each plot were examined separately, the figures in Table 3 being means of three determinations.

TABLE 3. *Bukalasa. Regeneration under Elephant Grass. Keen-Raczkowski Box Data*

Treatment	*Apparent spec. grav.*	*Air-dry moisture %*	*Pore space %*	*Water absorbed per gm. of soil*
1 year grass	114·1	3·58	52·6	0·516
2 years' grass	115·9	3·25	51·5	0·490
3 years' grass	111·6	3·24	53·7	0·521
1 year cultivation after 3 years' grass	114·0	3·57	53·8	0·517
2 years' cultivation after 3 years' grass	113·8	3·81	52·4	0·509
3 years' cultivation after 3 years' grass	113·3	3·71	53·7	0·520
6 years' orchard mulched	119·4	3·36	50·7	0·475

These samples were taken from plots under the normal Bukalasa rotation of 3 years' rest followed by 3 years' cultivation. Again the plots were not replicated and the results do not disclose any real trend. Agreement was good both within samples and between samples drawn from the same plot, but it was felt that the method dealt with the soil in an artificial rather than a natural state. Experiments by the method of Tiulin [3] as described by Russell [4] followed.

At first the complete bank of five sieves was used (2 mm., 1 mm., 0·5 mm., 0·25 mm., 0·125 mm.), the top sieve being removed as soon as it appeared to be clean. The fine sieves held up the work to such an extent that they were omitted from the bank, only the three larger sieves being used. When these were clean, the soil suspension was poured gently through the two fine sieves. This method reduced the time factor considerably and produced a much cleaner fractionation. After tests on a large number of samples from the same plot, the method finally adopted for use on the replicated field experiments was similar to that used at Rothamsted [4].

Laboratory procedure.—Samples drawn from the field are air-dried and after removal of roots and stones are passed through a 3-mm. wire-meshed sieve. No rubbing or mortar should be used, clods being gently broken down by the fingers. After mixing and quartering, 100-gm. samples are moistened by capillarity overnight before being transferred to the top member of the three-sieve bank (2 mm.). The sieves, 15 cm. in diameter, fit into each other and each joint is protected with sections of motor inner-tube, which also hold the wire handle in position. The bank is then lifted and lowered gently in a 4-gallon petrol tin of water until the fraction on the top sieve is well defined. The top sieve is then removed for air drying. The operation is repeated for the 1-mm. and ½-mm. sieves; the soil suspension is then poured slowly through the two fine 100- and 200-mesh sieves. The fractions are air-dried and weighed. These weights are read as percentages of the original sample.

The method was tried out on the samples which had already been examined by the box method and detailed in Table 3.

TABLE 4. *Bukalasa. Regeneration under Elephant Grass. Sieving in Water*

% *Water-stable particles of given diameter*

Treatment	*Over 2 mm.*	*2 mm.–1 mm.*	*1 mm.–0·5 mm.*	*Over 0·5 mm.*	*0·5 mm.–0·25 mm.*	*Over 0·25 mm.*	*0·25 mm.–0·125 mm.*
	1	*2*	*3*	*4*	*5*	*6*	*7*
1 year grass .	15·6	20·4	17·9	53·9	27·8	81·7	8·5
2 years' grass .	12·5	20·5	16·8	49·8	30·0	79·8	10·3
3 years' grass .	15·2	20·4	17·4	53·0	26·7	79·7	8·6
1 year cultivation .	14·8	20·3	17·3	52·4	27·5	79·9	8·2
2 years' cultivation	9·2	17·0	18·1	44·3	32·4	76·7	10·1
3 years' cultivation	12·5	18·4	18·1	49·0	31·0	80·0	8·9
6 years' orchard mulch . .	15·5	20·0	16·1	51·6	29·1	80·7	8·9

The first thing to decide is at what point in the scale of sizes should one enter, to be sure of obtaining a true picture of the soil structure, in so far as it affects the field properties of the land, in particular its pore space or penetrability by water. In this work all that is sought is a rapid and reasonably accurate means of assessing the value of a resting cover, or, on the other hand, the degree of deterioration or regeneration of arable land. For this purpose the ½-mm. point was decided on, partly because the use of the smaller sieves increases the time required inordinately, and partly because the majority of the particles larger than ½ mm. are aggregates, whereas greatly varying proportions of the residue on the ¼-mm. sieve are non-aggregated. In any case, under tropical rainfall conditions it is doubtful whether particles or crumbs smaller than ½ mm. exercise any beneficial effect on the water or air conditions of the soil.

In Table 4, col. 4 gives the sum of particles larger than ½ mm. and col. 6 includes the particles down to ¼ mm. What differences there may be are shown up better in col. 4 than in col. 6, where the addition

of 100-mesh material has tended to even things up.[1] In any case the differences are no wider by the wet-sieving method than they were by the Keen-Raczkowski box-method, but the general indications are similar and the wet-sieving process is more rapid and more logical.

Cultivation Effect

The effect of cultivation on structure is well illustrated by the results obtained from some soil samples from Barberton, South Africa.

The farm land has been cropped to cotton alternating with maize continuously for 15 years, during which time the land outside the boundary has carried a grass cover 1½–3 ft. high. This 'veld' land has been grazed. The samples are all composites of 10–12 top soils, taken to 9 in. The samples of the same numeral are from inside and outside the farm respectively, along a line at right angles to the boundary and 60 to 80 yds. apart.

TABLE 5. *Barberton. Effect of Cultivation*

% Water-stable particles over ½ mm. diameter

Sample	*Cultivated*	*Veld*
1	26·6	52·9
2	29·1	53·5
3	27·0	53·3
4	31·3	56·3
5	32·4	51·4
6	36·6	57·8
7	32·3	52·5
8	28·4	45·8
Mean	30·5	52·9

It is perfectly clear that the structure of the soil under a grass cover is far better than that under continuous cultivation. A portion of the veld has now been opened up and it is hoped that data may be obtained later on its rate of deterioration under cultivation.

Field Experiments

In all the work which follows, five cores were taken from each plot with a sample of the Veihmeyer type; the samples were examined separately by the wet-sieving process. Volume-weight determinations were made at the same time, but the figures were so variable that the differences between treatments were not significant. It is probable that a sampler of the Coile [5] type would have been more efficient. All the following results are based on samples taken at the end of a complete cycle, unless otherwise indicated.

Effect of manures.—At Serere in 1933 a 5 × 5 Latin square was planted to compare varying dressings of farmyard manure applied in conjunction with a green-manure crop, lime+green manure, and green manure

[1] Later work indicates that it may be better to use the ½-mm. sieve only, instead of the bank of three sieves.

TABLE 6. *Serere. Manurial Experiment*

Yields in lb. per acre

Year 1932	*1933–4*	*1934*	*1934–5*	*1935*	*1936–7*	*1937*	*1937–8*	*1938*	*1939–40*	*1940*	*1940–1*	*1941*	*1942–3*	*1943*
Crop	Cotton	Millet	Cotton	Ground-nuts	Cotton	Millet	Cotton	Ground-nuts	Cotton	Millet	Cotton	Ground-nuts	Cotton	Millet
Control . .	390	1,861	445	1,073	560	441	431	281	302	Crop failed	172	979	243	268
Lime 2 tons . .	332	2,372	410	983	574	608	537	363	263		222	1,053	261	596
10 tons F.Y.M. .	390	2,403	579	1,073	755	589	859	437	468		367	1,349	438	736
20 tons F.Y.M. .	364	2,193	567	1,143	746	608	884	421	455		356	1,316	379	948
30 tons F.Y.M. .	283	2,399	577	1,193	798	768	1,007	410	465		429	1,365	382	1,452
Significant differences .	None	None	130	None	150	None	179	None	89		98	314	89	350

Manures applied in 1933 before cotton; and after ground-nuts in each succeeding course of the rotation.

TABLE 9. *Bukalasa. Manurial Experiment*

Yields in lb. per acre

Year	*1933–4*	*1934*	*1934–5*	*1935–6*	*1936*	*1936–7*	*1937–8*	*1938*	*1938–9*	*1939–40*	*1940*	*1940–1*	*1941–2*	*1942*
Crop	Early cotton	Ground-nuts	Late cotton	Early cotton	Ground-nuts	Late cotton	Early cotton	Ground-nuts	Late cotton	Early cotton	Ground-nuts	Late cotton	Early cotton	Ground-nuts
Control .	454	1,127	736	902	1,274	361	584	866	928	1,104	640	474	275	390
Cotton seed .	678	1,479	368	1,014	1,132	472	677	982	1,140	1,243	710	662	338	365
Green manure	554	1,107	766	934	1,303	397	603	939	955	1,187	795	491	407	365
Cotton seed G.M. .	665	1,227	831	1,006	1,244	424	756	848	996	1,141	640	599	376	365
Sig. diffs. .	None	162	150	None	None	None	None	None	None	None	None	106	None	None

Manures applied before early cotton in each course.

alone. The rotation followed is: 1st year: green manure, cotton; 2nd year: *Eleusine coracana*, cotton; 3rd year: groundnuts, green manure.

The manures applied before sowing the green manure in each course of the rotation were, in tons per acre: (1) no manure; (2) lime, 2; (3) farmyard manure, 10; (4) farmyard manure, 20; (5) farmyard manure, 30.

The plots when sampled for structure analysis had received their third dressing of manure. The yield and wet-sieving data are summarized in Tables 6 and 7.

TABLE 7. *Serere. Manurial Experiment*

Water-stable crumbs

Treatment	*Particles over ½ mm.*, %
Control	28·5
Lime 2 tons	26·2
F.Y.M. 10 tons	25·9
F.Y.M. 20 tons	27·9
F.Y.M. 30 tons	27·3
Significant difference	None

Farmyard manure.—The design and layout of the fertility experiment at Serere [6] gives scope for the consideration of the effect of farmyard manure applied in much smaller dressings. There are 15 rotations combined with 0, 2½-ton, and 5-ton dressings of manure. The aggregate analysis is shown in Table 8.

TABLE 8. *Serere Fertility Experiment*

Water-stable crumbs

Treatment	*Particles over ½ mm.*, %
Control	38·1
F.Y.M. 2½ tons	38·5
F.Y.M. 5 tons	38·0
Significant difference	None

Cotton seed.—A 4×4 Latin square put down at Bukalasa in 1933 compares the effects of heavy dressings of cotton seed, with and without a green manure, and green manure alone, on the maintenance of soil fertility. Cotton seed has been applied at 4 tons per acre in alternate years. At the time of sampling, the manured plots had received 16 tons of cotton seed in the previous 8 years. The data for yields and structure are given in Tables 9 and 10.

TABLE 10. *Bukalasa. Manurial Experiment*

Water-stable crumbs

Treatment	*Particles over ½ mm.*, %
Control	31·2
Cotton seed, 4 tons/acre biennial	28·1
Green manure (*Crotalaria juncea*)	26·6
Cotton seed, 4 tons + green manure	29·9
Significant difference	None

It would appear from these tables that no structural benefit is achieved by organic manures whether in the form of farmyard manure, cotton seed, or green manure. The flocculating action normally attributed to lime in the field does not lead to the formation of water-stable crumbs larger than $\frac{1}{2}$ mm.

The Resting Cover

(*a*) *Elephant Grass* (*Pennisetum purpureum*.)—At Bukalasa a 4 × 4 Latin square was put down in 1936 to compare resting periods of 2, 3, and 4 years under elephant grass with a natural-bush regeneration over 3 years. In other words, a planted resting cover is compared with the same cover achieved under natural conditions, since in many parts of Uganda the final cover under shifting cultivation is elephant grass.

TABLE 11. *Bukalasa. Rotation Experiment*

Treatment	*Particles over $\frac{1}{2}$ mm.*, %
2 years' grass + 1 year cotton	48·2
3 years' grass	57·1
*4 years' grass	63·1
3 years' natural bush	56·2
Significant difference	8·5

* Sampled in March 1941. The effective resting period was only just over 3 years.

(*b*) *Grass* v. *Legume*.—The Serere fertility experiment was designed to compare five types of resting cover, the main comparison being that of grass versus legume resting cover. The structure-analysis data from the first cycle are given in Table 12.

TABLE 12. *Serere. Fertility Experiment*

Treatment	*Water-stable particles over $\frac{1}{2}$ mm.*, %
A. Natural weeds and grass	39·2
B. Planted grass	39·1
C. Green manure lopped	36·8
D. Planted grass lopped	39·0
E. Green manure dug in	36·9

The grass planted was a mixture of *Cynodon plectostachyon* and *Chloris gayana*, but the final stand was almost pure Cynodon. The green manure was *Stizolobium deeringianum* (*Mucuna pruriens*). Lopping was intended to simulate grazing, as grazing of small plots was difficult at the time. In all future work the plots will be grazed.

The comparison green manure versus grass (C and E v. A, B, and D) is significant ($P > 0{\cdot}05$), an indication that grass is more effective on the whole than green manure. No other comparison in this group is significant. This is probably because it was found impossible to eradicate *Imperata cylindrica*, so that the differences between resting covers have probably been evened up, but the main comparison has not been masked.

(*c*) *Time of Rest*.—The Serere fertility experiment was also intended to give information on the time of rest. The results so far obtained are given in Table 13.

TABLE 13. *Serere. Fertility Experiment*

Treatment	*Water-stable crumbs, %*
4 years' cultivation .	35·6
1 years' rest . .	..
3 years' cultivation .	36·9
2 years' rest . .	..
2 years' cultivation .	42·0
3 years' rest . .	..

Both the linear and quadratic components of this sequence are positive and significant. Unfortunately the bad effect of extended cultivation and the good effect of extended resting are confounded and cannot be separated, a point which was not foreseen in the original design. The figures, however, speak for themselves, and bring out not only the fact that a resting cover regenerates structure, but also that cultivation operations normally have a destructive effect.

(*d*) *Rest and yield.*—We have as yet no statistical correlation between the type or time of rest and the yield or productive capacity of the soil. An experiment carried out on the Kampala Plantation before I had heard of the Tiulin wet-sieving idea sheds some light on the relative merits of elephant grass and a cover crop for the resting period. An experimental area, which had carried a regular succession of cotton and food crop each year for 6 years, was divided into 4 blocks, and 2 of each were planted to elephant grass and *Centrosema pubescens* in March 1933, and rested for 3 years. The cotton yield of each block had been recorded for each of the previous 6 years' cropping. In March 1936 one block of each cover was burnt over, the other first slashed and all the green material dug in. Sown to cotton in the 1936–7 season, germination was not good, particularly on the elephant-grass 'dug-in' plot. This was primarily due to the puffy nature of the soil after the incorporation of an excessive amount of organic matter 2 to 3 months earlier. A second crop of cotton was taken off in the 1937–8 season, and the mean yield of cotton in these 2 seasons is compared with the best yield obtained from the identical piece of ground in the 6 seasons of cropping prior to rest. The

TABLE 14. *Kampala Regeneration Experiment*

Yield of Seed Cotton in lb./acre

Season	*Plot*			
	C 1	*C 2*	*E 1*	*E 2*
1. 1928–9 . .	630	560	475	600
2. 1936–7 . .	443	540	582	785
3. 1937–8 . .	590	677	539	799
4. Mean of 2 and 3 .	517	608	560	792
5. 4 as % of 1 .	82	109	118	132

Plot C 1. *Centrosema pubescens* burnt off.
Plot C 2. *Centrosema pubescens* dug in.
Plot E 1. Elephant grass dug in.
Plot E 2. Elephant grass burnt off.

mean yields of cotton in lb. per acre over the whole experiment for the years 1927–33 inclusive were: 150, 570, 243, 194, 149, and 275; so the second season was used as a basis for comparison.

These figures are interesting, although they are of no value statistically. They suggest that it is better to burn off the grass stand, probably because of the puffiness, already noted, when huge amounts of organic matter were incorporated. It is hoped that, in time, the question of disposal of the residues of the resting cover will not be so serious because in elephant-grass country stall-feeding may be developed. Meanwhile it is of value to know that no harm is done if the grass is slashed, dried, and burnt before reopening. In this way plant-food material, drawn from deeper layers of the soil by a very active root-system, is returned to the surface and is available almost immediately. In the case of the legume it seems to be advisable to dig in the residues. The volume of organic matter is smaller and of better nitrogen balance. However, whether burnt off or not, the grass resting cover is demonstrably better than the legume.

The Soils

Although it may be rather early to attempt a diagnosis of the state of deterioration or regeneration of soils on the basis of their percentage of water-stable aggregates, the data given below are interesting in that they show up the difference between Bukalasa and Serere soils and to a smaller extent between the soils at Bukalasa and Barberton. Buganda soil in good heart after a period of just over 3 years under elephant grass contains about 60 per cent. of crumbs, a total which is halved after a period of continuous cultivation. Barberton shows a change from 50 to 30 per cent., and Serere also drops to about 30 per cent. except on a piece of land which has in the past had a large addition of sand-silt wash through erosion, where the figure is only about 20 per cent. These results, extracted from the above tables, are summarized for convenience in Table 15.

TABLE 15. *Summary of Variation in Crumb-formation with Place and Cultivation*

Table	*Description*	*Crumbs, %*
11	Bukalasa soil in good heart	60
11	Bukalasa soil after 1-year cotton	50
5	Barberton soil in good heart	50
13	Serere soil after 3 years' grass	40
13	Serere soil after one year severe cycle	35
5, 7, and 10	Continuous cultivation Barberton, Serere, and Bukalasa	30

Discussion

The data presented in this paper were obtained in the course of 10 years' work designed to obtain information that would lead to the best possible use of the grass rotation in Uganda. The last few years have seen a vastly increased general interest in this aspect of the maintenance of soil fertility, and the results are presented in the hope that they will

assist other workers in the same field, and that they will be of interest to a much wider circle confronted with the problem of soil conservation, especially in the tropics. I can make no attempt to discuss these results in relation to the recent bibliography of the subject with my rather limited access to the literature in war time, but Russell's monograph [4] provides a valuable background for the presentation of these results.

There seems to be no doubt whatever that cultivation reduces crumb structure on all soil types; the data from Barberton and Uganda give added weight to these findings.

Lime seems to have no effect on crumb formation, whether applied in conjunction with green manure or farmyard manure on our soils, a result which is in direct opposition to those of Tiulin and Ilmenev as reported by Russell. Organic manures as a whole have given disappointing results in Uganda with regard to structure formation. It is probable that, under tropical conditions, the added organic matter is oxidized or otherwise disposed of before it can be decomposed to colloidal dimensions. The binding power usually attributed to humus is due to its colloidal properties, which would not be evident if added organic matter were decomposed very rapidly, and particularly if a major part of its decomposition was the result of termite activity.

Grasses, on the other hand, are here shown to be particularly effective in crumb formation. This effect cannot be due to the amount of organic matter added, in view of the results discussed above. A grass has a very widely dispersed, stringy root-system, as opposed to the normal tap-root of the legume, and it appears that the difference between the grass and the legume in structure-generation lies in just this difference in root-systems. The root-forces in action along and between the widely dispersed fibrous roots of the grass, grip and bind the soil particles immeasurably better than those of the legume. All the soil profiles under grass and legume in this part of the world have brought out these differences. Studies of soil moisture over 2 years reveal that there is a wider range of moisture under the grass than under the legume. This rather exaggerated form of wetting and drying, coupled with the normal root-forces, may account for the higher efficiency of the grass.

It is important that no one should take these conclusions as suggesting that the use of organic manures has been in any way deprecated. Organic manures do increase yields, as may be seen in Tables 6 and 9, but they appear to have little or no effect in soil regeneration, and so fail as anti-erosion agents. The ideal is a combination of the grass rotation with manuring, either organic or artificial, so that regeneration of soil structure is coupled with the benefits of manuring. In this country of peasant farmers the solution may prove to be controlled grazing of the resting land in short-grass areas and possibly stall-feeding of cattle in elephant-grass country. In either case organic manure is available, although the second alternative involves extra labour for its distribution. Whatever method of resting-land management is adopted, it is essential that on reopening the land for cultivation no large bulk of organic material of low nitrogen status should be dug in. The final grazing of short-grass land should be as close as possible and elephant-grass stubble

should be cut at ground-level and burnt. After-cultivation should be reduced to the minimum compatible with economic returns. As trustees it is our duty to ensure the future of the people on the land; our aim should be to use a system of agriculture which will preserve the soil *in perpetuo*, even at the risk of slightly reduced current production. Conservation and not yield should be the yardstick of the system if these criteria be found in opposition. The grass rotation coupled with strip-cropping has every appearance of fulfilling these requirements. Work on the effects of different grasses on soil structure is proceeding.

Summary

Observations leading to the adoption of the grass rotation in Uganda are recorded.

Under local conditions lime makes no contribution to crumb formation, whether applied alone or with organic manure.

Organic manures in the form of green manure, cotton seed, or farmyard produce no increase in the number of water-stable crumbs; possibly because only a small fraction of the added organic matter attains colloidal dimensions.

All grasses regenerate soil structure, but there is considerable variation between them.

The formation of crumbs is basically dependent on the amount of clay in the soil, so that the grass rotation cannot be expected to be beneficial on soils of very low colloid-content.

A note on the extension side of this work has already been published by Kerr [7].

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REFERENCES

1. F. J. Veihmeyer, An Improved Soil-sampling Tube. Soil Sci., 1929, **27,** 147–52.
2. B. A. Keen and H. Raczkowski, The Relation between the Clay-content and Certain Physical Properties of a Soil. J. Agric. Sci., 1921, **2,** 441–9.
3. A. F. Tiulin, Questions on Soil Structure. II. Aggregate Analysis as a Method for determining Soil Structure. Perm. Agric. Expt. Stat., Div. Agric. Chem., 1928, **2,** 77–122.
4. E. W. Russell, Soil Structure. Imp. Bur. Soil Sci., 1938, Tech. Commun.
5. T. S. Coile, Soil Samplers. Soil Sci., 1936, **42,** 139–42.
6. W. S. Martin and C. E. J. Biggs, Experiments on the Maintenance of Soil Fertility in Uganda. E. Afric. Agric. J., 1937, **2,** 371–8.
7. A. J. Kerr, Empire J. Expt. Agric., 1942, **10,** 125–32.

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(*a*) (*b*)

SERERE SOIL REGENERATION EXPERIMENT

Showing soil profiles developed in three years under (*a*) *Tephrosia candida*, and (*b*) Elephant Grass (*Pennisetum purpureum*). In spite of excellent leaf-litter under the former, the structure of the soil has not been improved and compares unfavourably with the structure developed under grass.

KAMPALA GRASS PLOTS

Showing soil-structure development under different grasses. Scale, black and white inches.

THE USE OF ORGANIC AND INORGANIC MANURES WITH RICE: A CONTINUOUS FACTORIAL EXPERIMENT

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THE results of ten years of modern field experiments throughout agricultural China have shown that at least four-fifths of the soils of China are deficient in plant-nutrients and respond to applications of fertilizers. In a preliminary survey [1] it was pointed out that on most of these soils large increases in crop production are possible, and that it would pay the farmer to use fertilizers, since supplies of local manures are already fully utilized. The only way to secure these large crop increases is by the use of inorganic fertilizers.

For any long-term manurial policy in China one must consider not only the immediately beneficial effect of the fertilizers on crop yields, but also their slower, cumulative effects on the soils and on soil fertility. In the western world science and practice have shown that soil fertility can long be maintained by the correct use of inorganic fertilizers alone, although these may be attended with difficulties, and their unwise use may damage both soil and crops. Any nutrients (including 'minor' elements) which are deficient in the soil must be supplied; liming must be used on very acid soils, especially if sulphate of ammonia is also used; bulky, organic manures should be employed, when possible, in order to maintain the organic matter in the soil.

The problem in China is twofold: (*a*) To determine the nutrient requirements of the various soils and crops; and (*b*) to study the best way of using fertilizers. The present experiment was planned as the first of a series intended not simply to test the old and rather pointless question of 'organics *versus* inorganics' but rather to give information about the best way of using 'organics *plus* inorganics', with the crops and under the conditions of eastern Asia.

The main experimental crop was rice, and the location of the experiment, on a great alluvial plain [2], makes it to some degree representative of many of the rice-growing lands of the East. The manurial treatments were typical of those employed in Chinese agriculture and sometimes used or advocated for use in other eastern countries.

Because the soil of the experiment was believed to be fairly well supplied with phosphate, potash, and minor elements (like many other heavy alluvial soils), nitrogen was the only inorganic fertilizer element

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tested; one object of the experiment was to find out how long it is possible, or desirable, to use nitrogen alone as a fertilizer on such soils, when bulky organic manures are also used. The latter may be counted on to supplement the resources of other nutrients in the soil, at least for a time. Three different kinds of bulky organic manure were employed; it was not thought so important to test the effect of no organic manure as to include as many forms as possible in the comparison. It may be assumed that a good Chinese farmer will always use some organic manure. Liming was also included in the experiment, partly in order to find out whether the slightly acid paddy soils of the Chengtu Plain respond to liming, and also to allow for the potentially acidifying effect of the sulphate of ammonia.

The experiment was designed from the start as a continuous one, to provide information about the cumulative and residual effects of the various treatments. To study the residual effects, a winter dry-land crop is grown without manure, in rotation with the rice. For the first four winters of the experiment, rape seed was grown; now the winter crop is being changed to wheat. Both crops are commonly grown in rotation with rice on the Chengtu Plain.

In detail, the objects of the experiment were: (1) to compare the effectiveness, as basal manures for paddy rice, of three local, bulky, organic manures; (2) to compare the value, as nitrogenous top-dressings, of rape-seed cake and sulphate of ammonia; (3) to examine the need of lime on the soil of the Chengtu Plain; (4) to study the interactions of these treatments; (5) to obtain information over a series of years, examining both cumulative and residual effects. Information obtained from (4) and (5) is likely to be especially important in relation to future manurial policy in China.

The experiment was begun in the spring of 1938, and the results from five crops of rice and the four intervening crops of rape seed are now available for study. It is hoped to continue the experiment on the same plots for many years to come, so that cumulative effects will have every chance to appear.

Experimental

Design.—The experiment was a $3 \times 3 \times 2$ factorial design, laid out in a 6×6 quasi-Latin square. Thus there were two replicates of the 18 individual treatment combinations, but a much higher degree of replication for main effects and important interactions. The design was of the type shown by Yates [3]. Confounding was used in order to make possible the elimination of row and column effects, both the 3×3 first-order interaction and the second-order interaction being partially confounded. The latter was included in the estimate of error in the analysis, whilst the yields of treatment combinations involved by the former interaction were adjusted to eliminate row and column effects.

Treatments.—The factors employed were:

(B), local bulky organic manures, as basal manuring, at three levels: B_1 or N = night-soil; B_2 or C = compost; B_3 or G = leguminous green manure.

(T), nitrogenous top-dressings, at three levels: T_1 or O = *nil*; T_2 or S = sulphate of ammonia; T_3 or R = rape-seed cake; and
(L), lime, at two levels: L_0 = *nil*; L_1 = quicklime.

The *rates of application* of (B) and (T) were on an equal-nitrogen basis, of 6 catties of nitrogen per mow[1] throughout (approx. 40 lb. per acre); all organic materials were analysed each year and applied accordingly. The analyses of the materials are given later. For sulphate of ammonia (20·9 per cent. N), the quantity of fertilizer applied was 28·8 catties per mow (approx. 1¾ cwt. per acre), which may be regarded as a rather moderate rate of application for paddy rice, except that it is combined with a similar amount of nitrogen in the basal organic manures. For rape-seed cake the quantity of fertilizer applied was around 115 catties per mow (approx. 7 cwt. per acre): this is actually about three times the average rate of application used by farmers on the Chengtu Plain, although some farmers may use as much [4]. For the bulky organic manures the actual rates of application varied greatly from year to year, especially with night-soil, on account of the variation in composition of the materials. The five-year averages were, in catties per mow (approximate equivalents in brackets): night-soil, 1,925 (5·8 metric or long tons per acre); compost, 1,365 (4·1 tons per acre); green manure, 532 (1·6 tons per acre). These may not seem very heavy applications of organic manure, but, except for green manure, they are more than the average rates employed for rice by farmers on the Chengtu Plain. In other words, the conditions of this experiment, as far as rates of manuring are concerned, were rather better than the average, although probably no better than those of the best class of farmers.

Lime was applied as quicklime, at 60 catties per mow (approx. 3½ cwt. per acre) of CaO. On the Chengtu Plain, as elsewhere in Szechwan, lime is not often used with ordinary crops, but this rate of application is similar to that employed by farmers in east and south China. All treatments, including lime, were applied annually, either before or with the rice crop.

The *night-soil* used was the ordinary commercial mixture of human faeces and urine supplied by Chengtu dealers. As the analyses show, it was a highly variable material, doubtless containing differing proportions of faeces and urine in different years, and possibly sometimes adulterated with water. This is typical of the material employed by farmers generally. Further work on the composition of night-soil at Chengtu, and on changes during storage, as well as its use in agriculture, is reported by Richardson and Wang [5, 6]; it is enough to mention here that even the unadulterated material contains 90 to 95 per cent. of water. The applications of night-soil in this experiment are not likely to have added more than 100 catties per mow (6 cwt. per acre) of organic matter to the soil each year, and possibly less. Thus the night-soil would be no more effective than the rape-seed cake used, in maintaining the soil organic matter. This relatively low content of organic matter is one of the

[1] 1 catty = 1·10 lb. = 0·50 kg. 1 mow = 0·1647 acre = 0·0667 ha.

important differences between night-soil and the other animal excreta that are commonly employed as manures.

The *compost* used was a hot-fermented product made from rice straw and night-soil; in the years 1938–41 it was inoculated with a 'starter' consisting of a culture of thermophilic cellulose-decomposing bacteria, prepared and used for extension work by Dr. C. Y. Pan of the Szechwan Provincial Agricultural Improvement Institute. In 1942 cow-dung suspended in night-soil was the inoculating material, and the heap was turned twice before use, giving a better decomposed product.

The *green manure* consisted of broad-bean plants (*Vicia faba* L.). They were grown elsewhere, and weighed amounts were applied to the plots. The crop was usually at about the end-of-flowering stage when used; it was quite ligneous, and was allowed to ferment for several days before application.

The *bulky manures* were usually applied and hoed in a few days before the plots were flooded and the rice seedlings were transplanted. The rape-seed cake was crushed before use and applied, like the sulphate of ammonia, as a top-dressing on the surface of the water about 5–6 weeks after transplanting the rice. The lime was dusted on as a top-dressing, from 3 to 5 weeks after transplanting.

The *area of plots* was $\frac{1}{20}$ mow ($\frac{1}{120}$ acre), which is the usual size for rice manurial experiments in China, where the fields themselves are often very small. Each plot was $13{\cdot}05 \times 23$ (Chinese) feet or $4{\cdot}3 \times 7{\cdot}7$ metres. The rice was planted in rows 1·5 (Chinese) ft. apart and in 'hills' 1 ft. apart within the rows; the outside, guard, rows were discarded at harvest. The individual plots of the experiment were separated by permanent earthen dykes, with channels for flooding and draining the plots as desired.

The *experimental field* was within the Campus of West China Union University, south of Chengtu City, and for many years previously had been used for paddy rice and winter dry-land crops, under ordinary farm conditions.

The *soil* was the grey alluvial soil of the Chengtu Plain, belonging to the Great Soil Group of 'Non-calcareous alluvial soils' [7]; it was a rather heavy, silty clay loam (Chu's Chengtu Silty Clay series [8]) and slightly acid in reaction, as the result of long-continued paddy cultivation. Before the experiment began, determinations by Kuhn's barium-sulphate method gave a value for the top soil or cultivated layer, to depth 15 cm., of pH 6·1 (average for the whole field). Later determinations made during the experiment showed considerable seasonal fluctuations.

The irrigation-water on the Chengtu Plain contains a variable proportion of greyish silty material: little or none in winter, but more in summer. This silt is rich in mica, which gives a 'silky' appearance to the flowing water in summer. The silt is somewhat alkaline in reaction (pH 8·1 [2]), and it is doubtless rich in slowly available phosphate and potash. In addition to finely ground rock particles from the western mountains, the silt contains some soil eroded from the slope fields in these mountains, so that it may also carry some available nitrogen. A small quantity reaches the paddy fields of the plain every

year, especially during the spring flooding of the rice-land, but this amount must not be over-estimated, since it is not sufficient to prevent the soils from becoming acid. During the summer, when the water is richest in silt, relatively little is used for irrigation, because the fields are supplied with water by the monsoonal rains.

Thus the soil of the experiment may have received some small additions of available phosphate and potash from the irrigation-water each year; but probably very little nitrogen. Field experiments of the 'NPK-test' type, carried out on the Chengtu Plain since this experiment was begun, have generally shown considerable response to nitrogen, but little or none to phosphate, and none to potash, except on sandy soils or with special crops.

Agricultural.—It is hoped to publish full records of the agricultural details in the *Nanking Journal* of the University of Nanking. Late planting or harvesting of the crops could not always be avoided, because of labour shortages due to war conditions. Probably because of this, rice stem-borer (*Schoenobius incertellus* Walker and some *Chilo simplex* Butter) attacked the experimental crops rather severely in certain years, particularly in 1938 and 1941 (*v.i.*). This considerably lowered the yields of paddy rice (grain), although not the straw yields, and the grain/straw ratios were abnormally low in these years. Since the time of transplanting in these years was much later than that of the nearby farms, it is legitimate to treat their results as abnormal, and to exclude them in discussing the effects of the treatments during normal years.

Apart from these stem-borer attacks, and some lodging (especially with night-soil and sulphate of ammonia), the rice crop grew quite normally throughout the experiment; the yields obtained on the more heavily manured plots were similar to the average farm yield on the Chengtu Plain. The rape seed, on the other hand, grew poorly, perhaps because it was unmanured. (In practice, farmers usually manure the rape-seed crop rather heavily with liquid manure, which also supplies water during the dry winter season.) The rape seed was also attacked by a virus disease, notably in the winter of 1939–40, and after the four years reported here, its place as winter crop in the experiment is being taken by wheat. The growth of the rape seed in the field showed signs of great soil heterogeneity, associated possibly with the supply of subsoil moisture during the dry winters experienced in Chengtu. This affected certain plots or parts of plots, practically at random, and was responsible for a high coefficient of variability in the rape-seed results.

Analysis of organic manures.—The percentage of nitrogen, on a fresh or wet basis, in the various manures in the different years of the experiment was as follows:

Year	*Night-soil*	*Compost*	*Green manure*	*Rape-seed cake*
1938 . .	0·89	0·48	1·99	5·07
1939 . .	0·33	0·31	0·80	5·54
1940 . .	0·23	0·58	0·45	5·64
1941 . .	0·17	0·37	0·70	5·00
1942 . .	0·61	0·62	1·79	5·10

The great variability in the composition of the bulky organic manures hould be noted; this is typical of such manures, and is one reason why experiments on their value frequently give variable or contradictory results.

Results

The results are presented in sets of two-way tables, for each crop (grain or seed, and straw or stems separately), for individual years, and also for the means of 3, 4, or 5 years (see Tables 1–4). For the mean results of several years the standard errors of these means were based in the usual way on the squares of the standard errors for the individual years. This procedure, which was equivalent to pooling the variances, appears to be fully justifiable for the rice yields, which did not show a very large range in the variances in normal years; but with rape seed the range was considerably greater, and the pooled errors should not be used too rigorously.

For clarity and economy of space, the statement and discussion of results does not attempt to go into every detail, even with statistically significant effects. Generally, non-significant effects are disregarded, unless they were on the verge of significance or were repeated in several years. Attacks by pests or disease may damage certain treatments much more severely in some years than in others. They are especially liable to occur with grain yields, which show much greater fluctuations than straw yields, and are more susceptible to accidental influences quite outside the design of the experiment—including not only pest and disease attacks but also late sowing or late fertilizer application, lodging, bird-robbing, &c. Thus, although what matters most to the farmer is yield of grain, yet from the scientific point of view—in order to form the clearest picture of the comparative effects of the different manures, and especially of the availability of their nitrogen—the straw yields may be of equal or greater interest. If cultural conditions are good, including timely sowing and manuring, the farmer may expect to secure yields of grain nearly proportional to the yields of straw. The general growth of the crop, as measured by observations of individual plots shortly before heading or flowering time, is usually reflected closely in the yields of straw or stem, although accidents may cause discrepancies in the final yields of grain.

Yields of paddy rice (grain in husk) (Table 1).—The general means of the three normal years, 1939, 1940, and 1942, show that night-soil was the most effective, and green manure the least effective, of the bulky organic manures. Compost was significantly below night-soil, and green manure in turn was below compost, although the mean difference here was only barely significant. Turning to the individual years, night-soil appeared curiously ineffective, relative to the other basal manures, with grain yield in 1942 (although it was the most effective manure for straw in that year). This was due largely to bird-robbing, the night-soil plots ripening first and being more severely attacked. Lodging was also rather serious in 1942, especially on the night-soil plots. In the other years night-soil always gave most grain, whilst compost was about equal to green manure in 1939, and significantly better in 1940 and 1942.

The sulphate of ammonia and rape-seed cake were almost equal in their average effects over the three seasons, and both gave highly significant increases over no top-dressing. In the individual (normal)

TABLE 1. *Yield of Paddy Rice, Catties per Mow**

	O	*S*	*R*		*N*	*C*	*G*	*O*	*S*	*R*	*Mean*
1938 (S.E. for 3×3, ±11·7)											
N	199	190	204	L_0	199	96	118	145	128	140	138
C	102	84	103	L_1	196	97	113	151	118	137	135
G	142	95	109	Mean	198	96	116	148	123	139	136
1939 (S.E. for 3×3, ±17·9)											
N	403	449	499	L_0	448	334	392	327	411	435	391
C	308	383	365	L_1	453	370	339	321	431	410	387
G	262	431	404	Mean	450	352	365	324	421	422	389
1940 (S.E. for 3×3, ±18·6)											
N	474	477	495	L_0	472	468	422	427	480	456	454
C	483	465	476	L_1	492	481	465	477	462	498	479
G	400	472	459	Mean	482	475	444	400	471	477	467
1941 (S.E. for 3×3, ±31·4)											
N	230	255	327	L_0	276	241	244	216	255	290	254
C	245	193	288	L_1	265	244	184	217	207	269	231
G	174	245	222	Mean	271	242	214	216	231	279	242
1942 (S.E. for 3×3, ±14·2)											
N	374	405	402	L_0	392	434	380	347	417	442	402
C	386	474	467	L_1	396	451	440	378	460	449	429
G	326	436	467	Mean	394	443	410	362	438	446	415
Mean, 1939, 1940, 1942 (3 years) (S.E. for 3×3, ±9·8)											
N	417	444	465	L_0	437	412	398	367	436	444	416
C	392	441	436	L_1	447	434	415	392	451	452	432
G	329	446	443	Mean	442	423	406	380	444	448	424

* 100 catties per mow = 6 cwt. per acre = 7·5 quintals per hectare.

In all tables standard errors are given only for the 3×3 treatments (i.e. means of 4 plots). Those for other treatments are obtained by multiplying these values by 0·816 for the 3×2 tables, by 0·577 for the overall N, C, G and O, S, R means, and by 0·471 for the overall L_0 and L_1 means.

years the same result held good, except that the increases were not significant in 1940.

Liming, at the moderate rate here employed, caused a significant increase in the average grain yield over the three years, but in individual

years its effect was significant only in 1942, although it approached significance in 1940. On the whole, the response to lime has so far been so small and variable that it would scarcely seem worth using for rice by the farmers on the Chengtu Plain.

The *interaction of basal manures and top-dressings* was just significant in the means for the three normal years. The differences between the basal manures were much greater when no top-dressing was used; or, alternatively, the responses to the top-dressings differed considerably with the different basal manures. On the average, in the three normal years, none of the various combinations of basal manure and nitrogenous top-dressing differed significantly in grain yield. It would seem almost as though there were a 'ceiling' imposed by lodging, bird-robbing, &c., above which grain yields could not be raised under the conditions of the experiment.

One aspect of this interaction requiring a little more study is that shown by the yields of the three basal manures alone, without any nitrogenous top-dressing. Under these conditions some of the differences between the basal manures, already referred to as main effects, were considerably intensified. The green manure, although fairly high in nitrogen, was much less effective than either night-soil or compost, the differences being highly significant in most of the individual years as well as in the mean. This may, perhaps, be attributed to the green-manure crop being in a condition approaching maturity when used. Compost was markedly inferior to night-soil in 1939, but apparently (although not significantly) superior in later years. The results with the 5-year means, considered with the main effects, and straw yields, suggest that on the whole night-soil was more effective than compost, but that there might be considerable variations from year to year, a result due partly to variability in the general condition (including availability of nitrogen) of the two materials, and partly to selective lodging and bird-robbing.

The nitrogenous top-dressings were most effective with green manure, less so with compost, and least effective with night-soil, i.e. night-soil by itself was almost as effective a manure (for producing rice grain) as any other basal manure plus a nitrogenous top-dressing, supplying altogether twice as much nitrogen. Although this was true on the average and in two of the individual years, it was very far from true in 1942, so that perhaps it should not be too strongly stressed until further results have been obtained. From the point of view of manurial policy, this result may also be put the other way: that if it were wished to supersede the use of night-soil as a manure in China (for hygienic reasons), equally good, or on the whole slightly better, grain yields could be obtained by using suitable combinations of bulky organic manure, like compost or green manure, with nitrogenous top-dressings.

Finally, there is no evidence so far that sulphate of ammonia is inferior, in its direct or cumulative effects, to rape-seed cake; or that it could not be employed just as well as rape-seed cake to increase rice production, when used along with bulky organic manures. None of the individual differences between these top-dressings, with any basal manure, was significant in normal years.

The *interaction between basal manures and lime* was significant in the means for the three normal years, but in individual years it was significant only in 1939, when liming depressed the yield with green manure and increased it with compost. Since, in 1942, and to a less extent in 1940, lime increased the yield with green manure, it is evident that the interaction with lime was not a consistent one; it will be necessary to continue the experiment in order to decide whether lime is more beneficial with some organic manures than with others.

The *interaction between nitrogenous top-dressings and lime* was not significant, either in the pooled analysis of variance or in individual years. It came nearest to significance in 1940, when, as it happened, lime appeared more effective with either rape-seed cake or no nitrogen than with sulphate of ammonia. In view of this, one may not attach too much importance to the fact that in 1942 lime gave a highly significant response with sulphate of ammonia but little response with rape-seed cake: however, it is possible that this marks the beginning of the calcium-depleting effect of sulphate of ammonia on the soil. Later years of the experiment will help to decide this point. Even in 1942 and without lime, the difference between sulphate of ammonia and rape-seed cake was not significant: in other words, on soils such as that of the Chengtu Plain there appears no need to be concerned about possible deleterious effects of sulphate of ammonia on the soil and crop for five years at least.

The grain yields in the abnormal years, 1938 and 1940, when (as already noted) the crops suffered severely from rice stem-borer as a result of late planting, need but a brief mention. There was a selective attack of the borer on certain treatments, which is evident in the grain yields and which was confirmed by actual studies in the field: these will be reported in detail elsewhere (*Nanking Journal*). Compost and sulphate of ammonia seemed to suffer more severely than the other treatments, and thus they gave lower grain yields, notably in 1938. The differential attack might be related to infection from the composted rice-straw; to later maturity, in the plots receiving a late top-dressing of available nitrogen; and to a greater succulence or palatability of the tissues of the young rice in these plots. (It is well known, for example, that nitrogenous top-dressings increase the palatability of grasses for live-stock [9]).

It will suffice to give here, as an index to the severity of the rice-borer attack in different years, the mean values for the percentage of empty panicles: those occurring on stems attacked by the stem-borer. These were determined by counts of sample rows in each plot. The standard errors of the means are also given, these being the residual errors after analysis of variance has eliminated treatment, row, and column effects:

Rice Stem-borer Attack

Year.	*1938*	*1939*	*1940*	*1941*	*1942*
Empty panicles as per cent. of total	64·8	5·1	..	34·7	7·2
S.E. ±	0·05	0·01	..	0·18	0·07

(In 1940 the attack was negligible, and counts were not made.)

Yields of rice straw (Table 2).—Inspection of these results shows that the years (1938 and 1941), which were abnormal for grain yield, were much less so for straw yield. The various treatment effects were substantially similar in both 'normal' and 'abnormal' years. Apparently,

TABLE 2. *Yield of Rice Straw, Catties per Mow*

	O	*S*	*R*		*N*	*C*	*G*	*O*	*S*	*R*	*Mean*
1938 (S.E. for 3×3, ±17·4)											
N	558	621	570	L_0	557	517	484	463	569	526	519
C	457	589	508	L_1	608	519	493	490	591	540	540
G	415	529	521	Mean	583	518	488	476	580	533	530
1939 (S.E. for 3×3, ±25·6)											
N	636	740	695	L_0	673	659	636	638	669	661	656
C	667	694	676	L_1	707	699	670	652	729	695	692
G	632	664	664	Mean	690	679	653	645	699	678	674
1940 (S.E. for 3×3, ±36·0)											
N	704	695	814	L_0	686	626	614	583	684	659	642
C	598	682	612	L_1	790	635	632	637	702	718	686
G	529	702	639	Mean	738	631	623	610	693	689	664
1941 (S.E. for 3×3, ±23·7)											
N	573	610	600	L_0	581	592	521	490	594	611	565
C	501	639	661	L_1	608	608	494	503	593	614	570
G	416	532	574	Mean	594	600	508	496	594	612	567
1942 (S.E. for 3×3, ±29·0)											
N	593	724	715	L_0	679	597	579	561	650	644	618
C	541	675	663	L_1	676	656	572	524	699	682	635
G	492	624	612	Mean	678	626	576	542	674	663	627
Mean, 1938–42 (5 years) (S.E. for 3×3, ±12·1)											
N	613	678	679	L_0	635	598	567	547	633	620	600
C	553	656	624	L_1	678	623	572	561	663	650	624
G	497	610	602	Mean	656	611	570	554	648	635	612

although the stem-borer damaged the stalks and prevented the filling out of the panicles, its attack did not reduce the weight of the stalks (or straw, including leaves) nearly so severely as it did the weight of grain. This is reflected in the grain/straw ratios (ratios of general mean yields):

Year	*1938*	*1939*	*1940*	*1941*	*1942*
Grain/straw ratio . .	0·258	0·576	0·703	0·428	0·663

It is evident that the normal grain/straw ratio in this experiment was around 2/3, and this was lowered by the stem-borer attack, to a degree

varying with the severity of the attack. Inferentially, the borer had relatively little influence on the yield of the straw.

In view of these facts, it did not seem necessary to exclude the 'abnormal' years from the study of straw yields, and all five years of the experiment have been included in the general average at the bottom of Table 2.

The production of straw is not without practical or economic value, especially in China, where it is in such demand for fuel, feed, and thatching that it is rarely used for making farmyard manure or compost.

The results for straw agreed in general with those for grain, except that the various main effects were more clearly and consistently shown, and the 'ceiling', which was observed with average grain yields, did not occur with straw. The straw yields may be taken as giving a better index than the grain yields to the relative *availability of the nitrogen* in the various manures.

Thus, the nitrogen of the night-soil was more readily available than that of the compost, and this in turn than that of the green manure. The differences between the different basal manures were all highly significant in the five-year averages and usually in the individual years.

There is no evidence, in the results for 1942, that the more slowly acting organic manures have built up any appreciable reserves of available nitrogen in the soil, as compared with the quick-acting night-soil, even after five years of use. There was, on the average, a large and highly significant response to either form of nitrogen. In all but one of the individual years, as well as in the five-year average, sulphate of ammonia gave a higher yield than rape-seed cake, although the difference was only once significant, in 1938. It would thus appear that the nitrogen of the rape-seed cake was slightly less available than that from the inorganic source, even under the warm, moist, conditions of paddy cultivation. There was no evidence of any deleterious cumulative effect of sulphate of ammonia, as compared with rape-seed cake, during these five years of experiment.

Liming gave a significant positive effect in the five-year average, with rice straw as with the grain. The effect was, however, not large, and it did not quite reach significance in any of the individual years, although it was shown in all of them.

The results showed, as with grain so still more with straw, that should the direct application of night-soil be discontinued in China, yields could be maintained, or raised to a still higher level, by suitable combinations of bulky organic manure and inorganic nitrogen. Here, the straw yield with compost plus sulphate of ammonia was significantly higher than that with night-soil alone (supplying, of course, half the total amount of nitrogen); whilst the yield with green manure plus sulphate of ammonia was practically the same as that with night-soil alone.

The interactions with lime were not significant. The response to lime with sulphate of ammonia was no greater than that with rape-seed cake, on the average, and but little greater in 1942, so there is no real evidence as yet of any deleterious acidifying action of the sulphate of ammonia.

It is possible that, eventually, one or other of the basal organic

manures may prove to have especial advantages when employed with inorganic nitrogen by meeting the extra demand on phosphate and potash which the use of nitrogen entails. It cannot be said that there is yet any sign of this effect in either grain or straw yields. The most evident thing so far is that night-soil (used at the rate employed in this experiment) is such a good source of rapidly available nitrogen that an additional top-

TABLE 3. *Yield of Rape-seed Seed, Catties per Mow (Harvest Years)*

	O	*S*	*R*		*N*	*C*	*G*	*O*	*S*	*R*	*Mean*
1939 (S.E. for 3×3, ±4·88)											
N	65·9	47·0	63·5	L_0	68·0	65·5	59·9	74·0	55·9	63·5	64·4
C	68·2	52·9	54·1	L_1	49·6	51·4	65·5	56·8	51·0	58·7	55·5
G	62·0	60·5	65·6	Mean	58·8	58·4	62·7	65·4	53·5	61·1	60·0
1940 (S.E. for 3×3, ±0·24)											
N	1·97	2·03	1·95	L_0	2·02	1·85	2·38	2·18	2·07	2·00	2·08
C	1·65	1·67	1·57	L_1	1·96	1·41	2·46	1·81	2·07	1·95	1·94
G	2·36	2·52	2·38	Mean	1·99	1·63	2·42	1·99	2·07	1·97	2·01
1941 (S.E. for 3×3, ±5·46)											
N	33·7	14·8	20·4	L_0	33·5	31·3	18·5	39·0	24·1	20·2	27·8
C	33·0	25·1	16·5	L_1	12·5	18·5	24·8	20·8	13·9	21·0	18·6
G	22·9	17·0	24·8	Mean	23·0	24·9	21·6	29·9	19·0	20·6	23·2
1942 (S.E. for 3×3, ±4·03)											
N	26·6	21·5	22·8	L_0	26·5	19·0	25·9	25·0	21·4	25·0	23·8
C	20·5	21·7	20·7	L_1	20·9	22·9	25·0	23·4	23·1	22·2	22·9
G	25·5	23·5	27·3	Mean	23·6	21·0	25·4	24·2	22·2	23·6	23·3
Mean, 1939–42 (4 years) (S.E. for 3×3, ±2·09)											
N	32·0	21·3	27·2	L_0	32·5	29·4	26·7	35·0	25·9	27·7	29·5
C	30·8	25·4	23·2	L_1	21·2	23·6	29·4	25·7	22·5	26·0	24·7
G	28·2	25·9	30·0	Mean	26·8	26·5	28·0	30·4	24·2	26·8	27·1

dressing of nitrogenous fertilizer is likely to be uneconomic. The combined application (12 catties of nitrogen per mow) appears to be rather excessive for paddy rice on this soil. Possibly the smaller dressings of rape-seed cake actually used by farmers, to supplement night-soil, are more economic than that used in this experiment. With other basal manures, which are richer in organic matter but whose nitrogen is less readily available, the rates of application used appear to be reasonable.

Yields of rape seed.—These are shown in Tables 3 (seed) and 4 (stems), for the four harvest years, 1939–42, during which rape seed was the crop grown. This winter crop was not manured. As already mentioned, the growth of the rape seed was rather poor, especially during the second

winter; and there was great heterogeneity, so that standard errors were relatively high.

None of the basal bulky *organic manures* differed significantly in the four-year averages, with either seed or stem yield. For seed in 1940 green manure was significantly better than either compost or night-soil.

TABLE 4. *Yield of Rape-seed Stems (Dry), Catties per Mow (Harvest Years)*

	O	*S*	*R*		*N*	*C*	*G*	*O*	*S*	*R*	*Mean*
1939 (S.E. for 3×3, ±25·4)											
N	248	166	224	L_0	254	247	221	282	200	240	241
C	267	199	187	L_1	171	188	243	203	183	215	200
G	213	211	271	Mean	212	218	232	243	192	227	221
1940 (S.E. for 3×3, ±2·83)											
N	24·7	19·9	23·6	L_0	23·7	23·2	23·4	27·7	21·0	21·6	23·5
C	29·2	18·4	16·1	L_1	21·6	19·2	24·4	21·6	20·7	22·9	21·8
G	20·2	24·8	27·3	Mean	22·7	21·2	23·9	24·7	20·9	22·3	22·6
1941 (S.E. for 3×3, ±9·81)											
N	61·3	32·0	35·2	L_0	57·7	53·6	40·4	68·4	41·3	42·0	50·6
C	61·9	40·3	35·0	L_1	27·9	37·9	42·5	39·1	29·0	40·1	36·1
G	38·3	33·1	53·0	Mean	42·8	45·7	41·5	53·8	35·1	41·1	43·3
1942 (S.E. for 3×3, ±14·71)											
N	99·6	87·1	90·0	L_0	108·1	91·4	96·3	110·3	88·1	97·4	98·6
C	97·0	86·3	88·4	L_1	76·4	89·8	105·1	92·6	91·2	87·4	90·4
G	107·7	95·5	98·9	Mean	92·2	90·6	100·7	101·4	89·6	92·4	94·5
Mean, 1939–42 (4 years) (S.E. for 3×3, ±7·76)											
N	108·3	76·2	93·2	L_0	110·9	103·8	95·2	122·2	87·7	100·2	103·4
C	113·8	86·0	81·6	L_1	74·2	83·7	103·6	89·1	81·1	91·3	87·2
G	94·9	91·0	112·6	Mean	92·5	93·8	99·4	105·6	84·4	95·8	95·2

The tendency for green manure to be higher than the other manures was shown also in all the other years except 1941, and in the general averages, with both seed and stems, so that it probably represents a real effect.

Thus we may conclude that the basal manures differed very little in their residual effects during the first four years of the experiment, in spite of the wide differences in the direct availability of their nitrogen. There was some evidence that the one, green manure, whose nitrogen was the least available, was the one with the greatest residual effect for the winter crop: but the extra effect in winter was small in comparison with the deficit in its effect in summer.

There was only one significant effect for *nitrogenous top-dressings* in individual years: namely, a depression after sulphate of ammonia for seed in 1939. This effect was also significant for the average of four years in both stems and seed. In each individual year, as in the averages, rape-seed cake was also below nil, with both seed and stems, though the effect did not reach significance. Usually, also, the yield with rape-seed cake was a little above that with sulphate of ammonia.

One may infer that the extra growth of rice which was secured by the nitrogenous top-dressings took some extra plant-nutrients out of the soil, so that the following unmanured crop suffered a little in consequence. The effect was clearer with sulphate of ammonia than with rape-seed cake, which, of course, supplied a little phosphate and potash along with its nitrogen. As with the basal manures, however, the residual effect was a small one—far less than the response secured by nitrogen with the summer crop—and it would easily be counteracted by the rather heavy manuring which a winter crop usually receives in China.

Liming, somewhat unexpectedly, depressed the average yield of seeds and stems, the effect being significant in the four-year averages and in the individual years 1939 and 1941. There was, however, the complication that this depression occurred with night-soil and compost, but not with green manure. It is possible that this result depends on irregularities in the soils or subsoils of certain plots, which may not have similar effects on the future wheat crops. It would be better, therefore, to reserve judgement on the apparent residual action of liming.

The other interactions, between *basal manures and top-dressings*, and between *top-dressings and lime*, were not significant with either seed or stem yields in any year. This would suggest that the residual effect of nitrogenous fertilizers was due to partial exhaustion of phosphate, and/or potash, rather than of calcium.

On the whole, it can be said that the *residual effects* of the treatments applied to the rice crop during the first five years of the experiment have been small as measured by the yield of the following winter (rape-seed) crop. Whether beneficial with some treatments or deleterious with others, they have been far less than the direct effects of the treatments on the rice; where, as with green manure, the direct effect was rather small, the residual effect was not sufficient to compensate for this: and where, as with nitrogenous fertilizers, there was a slightly deleterious residual effect, it was not worth off-setting against the large direct responses observed with both rice-grain and straw yields. Possibly the residual effects will become more marked as time goes on: this is one reason for continuing the experiment as long as possible.

Conclusions

It would be unwise to generalize the results of this one experiment too widely, or to take it alone as a basis for future policy in Chinese agriculture. Experiments of the same type have been laid out in other parts of China, and their results will in due course be considered. Nevertheless, the soil and other conditions were quite representative of those of

the Chengtu Plain as a whole; and from the point of view of plant nutrition, the results are probably applicable to many of the other rice-growing alluvial soils of eastern Asia, as well as to the purple-brown soils of the Red Basin of Szechwan: to all paddy soils, in fact, which have a fairly high base-status, and which receive a certain amount of silt, containing available phosphate and potash, in the irrigation-water each year. They may be less applicable to highly leached and phosphate-deficient paddy soils, especially if these receive irrigation-water poor in plant-foods, or are chiefly irrigated by rain-water.

Briefly, the results show that on soils of the kind mentioned it is possible to increase rice yields and maintain soil fertility by using a basal manuring of bulky, local, organic manure, supplemented only by a nitrogenous fertilizer.

Looking to the future and contrasting the limited supplies of oilseed cakes with the inexhaustible reserves of atmospheric nitrogen, it is inevitable that the nitrogenous fertilizer used will usually be an inorganic one. The experiment has shown that for the first five years, at least, the inorganic fertilizer is under no disadvantage as compared with the organic one, when basal organic manure is also used. It is possible that with an inorganic fertilizer, such as sulphate of ammonia, which tends to acidify the soil, liming will later become necessary; but in the present experiment signs of this need were only doubtfully beginning to appear in the fifth year. The unbalanced nitrogenous fertilizers may have tended slightly to exhaust the soil for the following winter crop, but so far the effect was trifling, and such as would be completely obviated by the manuring which the winter crop would normally receive.

These results agree with those of the classical experiments on continuous manuring in the western world, and from the results obtained in those experiments it may be expected that many years will elapse before large cumulative or residual effects begin to appear. The present experiment differs from the older ones in being carried out with paddy rice instead of the dry-land crops of the West, so that soil conditions during the summer are entirely different. Owing to the mild climate of the rice region a winter (dry-land) crop can be grown in rotation with the rice, and thus the residual effects as well as the cumulative ones can be measured directly. As the experiment is of modern, factorial, design, it is possible to study interactions of treatments as well as main effects, and to apply valid tests of significance. Some of these interactions are likely to be of great practical importance.

The results obtained with bulky, local, organic manures have an important bearing on future policy. The use of night-soil directly as a manure is difficult to defend on grounds of public health, and the amount of organic matter it adds to the soil has probably been overestimated in the past. Night-soil is more comparable with an organic nitrogenous fertilizer like oilseed than with other bulky organic manure. If it is skilfully composted, its use would be much more hygienic, and at the same time more effective in maintaining the soil organic matter. The direct manurial value of the night-soil is, however, reduced by composting it; but this can be more than made good by a moderate top-dressing

of inorganic nitrogenous fertilizer. Consequently, the combination of a basal manuring of compost (preferably made with night-soil) and a nitrogenous top-dressing seems to be a very promising system of manuring in China, with a view to the maintenance or improvement of soil fertility. (On very phosphate- or potash-deficient soils, P or K should, of course, be applied as well as N; and on very acid soils lime will also be needed.)

The results with green manure indicate that this system is inferior to composting. There are, however, other matters to be considered, namely those connected with the general management of the farm. The winter green-manure crops grown by the farmers are often partially used for fodder (as well as for human consumption), so that their occupation of the land serves more than one purpose. Further, it may prove more difficult to persuade farmers in the East to use straw for composting than to grow a leguminous green manure; and again, compost made under ordinary farm conditions will often not be as effective a manure, or as hygienic, as that prepared under scientific control. Consequently, leguminous green manuring may still be recommended as an alternative source of bulky organic manure to compost. In the present experiment the rice receiving green manure responded even more than that receiving compost to a moderate top-dressing of inorganic nitrogen. Thus the application of nitrogenous fertilizer may be recommended, on such soils as this, where a moderate amount of green manure is used with rice.

The rate of application of green manure in this experiment (averaging 532 catties per mow) was less than that which might be expected when a full crop of green manure is turned under in the field where it is grown. Although it is a common practice in China to remove part of a green-manure crop for fodder, for compost, or for manuring other fields, yet if the full crop were turned in it would doubtless be a more effective (because more plentiful) source of nitrogen than in this experiment; and nitrogenous top-dressing might be less effective. Thus, Chang, Yao, Yieh, and Chang [10] found, with winter wheat, that when *mung* or green beans (*Phaseolus aureus*) were grown on the plots, and the whole crop was ploughed under a month before sowing the wheat, then there was a large response to the green manure, which almost obscured the response otherwise given to nitrogenous fertilizer. The amount of nitrogen applied in the green-manure crop in this wheat experiment was probably much greater than that in the Chengtu rice experiment.

Chang *et al.* [10] also reported results on the comparison of organic and inorganic forms of nitrogen with winter wheat at Nanking, which agreed in general with those reported here. Comparing sulphate of ammonia with oilseed cakes, in different experiments and for several years, they found that on the average the inorganic and the organic forms of nitrogen were about equally effective. No deteriorating effects on soil properties were noticed after three years' fertilization.

A comparison of organic and inorganic manures was made in North China (Tsinan) by C. Winfield, in co-operation with the National Agricultural Research Bureau. In a continuous experiment, extending over several years with wheat and millet in rotation, he showed that dried,

human, faeces in cake-form, were as effective a source of nitrogen as sulphate of ammonia, whilst Indore compost, and pig-pen manure, were less effective (all on an equal-nitrogen basis). The former two were to be regarded as quick-acting, and the latter two as slow-acting, manures. The residual effects of the slow-acting manures were slight (unpublished data).

From the results of the Chengtu experiment there is no need to urge farmers growing rice on this type of soil to adopt liming, unless the lime is readily and cheaply obtainable in the locality. This is true although the soil of the experimental field was slightly acid when the experiment began. Even the winter crop (rape seed), which might have been expected to be less tolerant of acidity than rice, showed no advantage from the residual effects of the lime used for the rice.

Summary

(1) The yield results of a continuous, factorial experiment on the use of organic and inorganic manures are presented and discussed. The experimental field was paddy land, located on the alluvial soil of the Chengtu Plain, West China; the main crop was rice, and residual effects were studied on a winter crop of rape seed.

(2) There were three factors in the experiment: (i) basal, bulky, organic manure; (ii) top-dressing with inorganic and organic nitrogenous fertilizers; (iii) liming. Factor (i) was present at three levels: (*a*) night-soil; (*b*) compost (made from night-soil and straw); (*c*) leguminous green manure. Factor (ii) was also at three levels: (*a*) nil; (*b*) sulphate of ammonia; (*c*) rape-seed cake. Factor (iii) was at two levels; (*a*) nil; (*b*) lime. The materials in factors (i) and (ii) were applied on an equal-nitrogen basis, viz. 6 catties per mow (40 lb. per acre) of total nitrogen, with each factor.

(3) The layout of the experiment was a $3 \times 3 \times 2$ factorial design, with two replicates, arranged in a 6×6 quasi-Latin square, with partial confounding of some interactions. Plots were $\frac{1}{20}$ mow ($\frac{1}{120}$ acre).

(4) Of the basal organic manures night-soil was clearly the most effective with rice, compost and green manure following in that order. In its residual effect upon rape seed, the green manure was a little better than the other two.

(5) Nitrogenous top-dressing gave large responses with rice, grain and straw, and the two forms were about equally effective. The least effective of the basal manures permitted the largest response to added nitrogen in grain, all combinations of basal manures and nitrogenous top-dressings giving about the same average yields. With rice straw the yields with nitrogen remained in the same order as those without nitrogen. The rape-seed crop showed indications of a small reduction in yield when nitrogenous top-dressings had been used with rice, particularly after sulphate of ammonia, but the effect was one that would be negligible in practice.

(6) Liming somewhat increased the yield with rice, but with rape seed there was a slight decrease. The effects were, however, small and irregular.

(7) The application of these results to future manurial policy in China is briefly discussed. They demonstrate that the fertility of alluvial paddy soils, such as those of the Chengtu Plain, can be maintained, or even increased, by the use of compost or green manure instead of night-soil, if supplemented by a moderate dressing of inorganic nitrogenous fertilizer.

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REFERENCES

1. N. F. CHANG and H. L. RICHARDSON, Soil Fertility and Manuring in China. Nature, 1942, **149**, 410.
2. H. L. RICHARDSON, Soils and Agriculture of Szechwan. Nat. Agric. Res. Bureau (China), 1942. Spec. Pub. No. 27.
3. F. YATES, The Design and Analysis of Factorial Experiments. Imp. Bur. Soil Sci., 1937. Tech. Comm. No. 35.
4. C. L. FENG, Summary of Manurial Practices in Szechwan. Soil Quarterly (Nat. Geol. Survey China; in Chinese), 1943, **3**, No. 1.
5. H. L. RICHARDSON and Y. WANG, The Nitrogen Conservation of Night-soil in Central China. Soil Sci., 1942, **54**, 381-9.
6. —— Observations on the Use of Night-soil as a Manure in Szechwan. J. West China Res. Soc., Ser. B (in Publication).
7. J. THORP, Geography of the Soils of China. Nat. Geol. Surv. China, Nanking, 1936.
8. L. T. CHU, A Reconnaissance Soil Survey of Chengtu Area, Szechuan. Nat. Geol. Surv. China, 1937. Soil Bull. No. 18.
9. W. E. J. MILTON, Empire J. Expt. Agric., 1934, **2**, 51–64.
10. N. F. CHANG, K. K. YAO, H. T. YIEH, and S. C. CHANG, Fertilizer Experiments of Wheat, 1933–6. Nanking Journal (University of Nanking), 1937, **7**, 39–63.

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THE WAR-TIME FEEDING OF CONCENTRATED FOOD TO PREGNANT RABBITS

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In previous experiments, described by Dennis Page (this Journal, 1942, **10**, 103–16), the extent to which concentrated food, in addition to hay and green-food or roots, is essential for healthy litters and satisfactory meat production was investigated. Preliminary work had revealed that hay and succulents, although adequate for maintenance, were insufficient for production. Accordingly, investigation was directed towards determining how much concentrated food should be provided for the doe during suckling and for the rearing of the young up to killing-size. It was found that this requirement was far in excess of the ration issued by the Ministry of Agriculture, viz. 28 lb. per breeding doe per year, and that cooked potatoes could be successfully substituted, as a supplementary food of higher nutritional value than hay and succulents, for the more usual oats, maize, or bran of peace-time. These experiments were concerned with the feeding of concentrate during two periods of rearing—a suckling period up to 48 days and growth of young from weaning up to killing-size. In these trials maiden does receiving up to the time of kindling a ration of oats or potatoes as rearing concentrate, and older does fed before kindling upon the maintenance feed of hay and succulents only, were grouped together. The object of the experiment here described was to ascertain whether the feeding of concentrate to the pregnant doe before parturition is of real importance in its effect upon birth-weight and lactation of the doe, and thus upon the growth of young during the vitally important first months of growth and meat production.

The general plan of experiment has been as follows: Does have been fed either on a pelleted mixture: (pounds) middlings 22·5, maize 19, oatmeal 7·5, bran 11, decorticated earth-nut cake 11, dried yeast 4, and (ounces) salt 2·7, bone-meal 6·5, chalk 6·5; or steamed potatoes (plus 1 per cent. salt) on equivalent dry-matter basis, during the last 10 or 20 days of pregnancy.

Trials were set up with the following groups on different rations. They were so designed as to obtain, apart from the simple comparisons possible within each main group, a comparison between the results of feeding equivalent rations of the pelleted mixture and potatoes, and also some indication of the amount of prenatal concentrate, if any, necessary for the production of an increased birth-weight and the range of greater birth-weight necessary for a sizeable effect upon the growth of young.

The maintenance feed consisted of sainfoin or seeds, hay, and mangolds throughout the late autumn, winter, and spring months; and of hay and lawn-clippings or rough grass, or occasional cabbage, from May onwards.

Daily Rations fed to Does

Ration before kindling	*No. of days fed*	*Ration during suckling*
3 oz. pellets . .	20	4 oz. pellets
3 oz. pellets . .	10	4 oz. pellets
. .	. .	4 oz. pellets
2 oz. pellets . .	10	3 oz. pellets
. .	. .	3 oz. pellets
12 oz. potatoes .	20	16 oz. potatoes
12 oz. potatoes .	10	16 oz. potatoes
. .	. .	16 oz. potatoes
8 oz. potatoes . .	10	12 oz. potatoes
. .	. .	12 oz. potatoes

Cross-bred does have averaged 7 lb. in weight at mating and were reared on oats or potatoes; age has varied between $2\frac{1}{2}$ and $1\frac{1}{4}$ years, and the majority of litters have been 2nd and 3rd litters. The prenatal concentrate treatments were distributed among 24 does, the control treatments among 18. The buck used was a pure Blue Beveren (live-weight 8·5 lb.); he received as his concentrate food the pelleted mixture. The young were kept as litter mates until 88 days, receiving each 1 oz. pelleted mixture or 4 oz. potatoes.

Food consumption has been measured during the period of mangold feeding, from November to mid-May, during if possible the resting period, pregnancy, and lactation. It was not always possible to obtain figures for the hay consumed as it was sometimes too soiled for accurate measurement.

Total mortality of the young has been 25 per cent.: 12 per cent. of deaths occurring before weaning, 13 per cent. during the period 48–88 days. The majority of deaths were accompanied by heavy scouring, and post-mortem examination usually revealed symptoms of coccidiosis. The distribution of mortality has shown no significant association with the treatment of the doe.

From the limited individual data obtained the main indication is a negative one: the feeding of concentrate during pregnancy does not play an important part in the subsequent growth of the young. Limitation of space precludes detailed numerical information; should, however, this be of interest, it can be obtained direct from the School of Agriculture, Cambridge.

During pregnancy the appetite of the does has shown an unexpected general trend of decrease, in the case of both prenatal concentrate treatments and controls. In measuring the food consumption, the time of pregnancy has been divided into three 10-day periods from mating onwards. The average consumption of mangold per day during these three periods has been marked by a distinct fall. The consumption of hay varied somewhat and in general has shown a similar decrease; it certainly has not risen. Nor have the does always consumed a fair proportion of the ration of concentrate provided (in all groups), particularly during the last 4 or 5 days of pregnancy.

The does have been weighed at corresponding 10-day intervals. Notwithstanding this decrease of appetite, they have usually shown in both pellet and potato groups a rise in weight beyond that of the weight of litter born, and this increase is disposed irregularly among the three 10-day periods of pregnancy. Thus increase in weight during the first or second 10-day period after mating may be of the same order as, or even greater than, that during the last 10-day period before kindling, i.e. during the period of the maximum growth of foetus. Decreased capacity of body-cavity due to growing litter and possible fat-deposition have, it would appear, been coincident with the decreased appetite. One or two individual does have shown during their pregnancy a lower final weight compared with the weight at mating; some show increases of weight between mating and kindling insufficient to cover the weight of litter born. These changes in weight are clearly not compatible with the weight of embryonic tissue developed; some utilization of the body reserve of the doe has evidently occurred. Thus, whether additional concentrated food will be fully utilized by the pregnant doe under war-time conditions of low-protein diet throughout the life of the doe and at times of poor green-food is by no means certain.

Average birth-weights of litters from does fed on the pelleted mixture or potatoes have been significantly higher than those from does receiving no prenatal concentrate. In the average growth of the young, the effect of litter-size upon weight has been evident within each main group and sub-group, where a bigger litter has the advantage of an equal or somewhat greater average birth-weight than a smaller litter. For the same litter-size, litters of bigger birth-weights have shown, where a few comparisons are possible, in some cases slightly greater average weight: at weaning, 1–3 oz. more. In others no possible advantage is apparent. Such small differences observed are within the limits of normal variation in weight: whether any advantage of greater birth-weight is retained or not and, if it is retained, the range of birth-weight necessary for its retention, cannot be settled without more data. However, any possible advantage at killing-age would be *slight*.

From such results the conclusion is reached that under war-time conditions in general the feeding of concentrate during pregnancy is not important: greater birth-weights on the average are obtained by the use of concentrates, but overwhelmingly more important are adequate food during suckling and the arbitrary limitation of litter-size.

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REQUIREMENTS OF THE POTATO ON ACIDIC BRACKEN LAND

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MUCH has been learnt during recent years regarding the capacity of Welsh upland soils for the growing of improved grasses and arable crops. In the more shallow fescue-dominant soils water-supply is the limiting factor, and here the most durable improvement is obtained by the growth of a soil-ameliorating crop such as rape, followed by re-seeding. The nardus soils with their greater depth and accumulation of organic matter have—with suitable cultivation and manuring—responded exceptionally well to direct re-seeding. The *Molinia*-dominant soils, which are rich in organic matter and have a substratum of clay, can carry a cereal such as wheat, rye, or oats, after a process of amelioration, as indicated above, prior to re-seeding.

Of all the soils previously derelict that have recently grown arable crops, none is of greater interest than the bracken-dominant type covering large areas of these uplands. A full account of the methods employed in reclaiming these areas in Montgomeryshire has been published by Marriott and Elison (*J. Landagents' Society*, Jan. 1942, Mar. 1943). The bracken areas of greatest economic value are those where tall luxuriant bracken has thrived for many decades and enriched the surface-soil with its decaying fronds. The soils are of a type that differ in important physical and chemical properties from others at the same altitude, and have yielded results which in certain respects are exceptional.

Mechanical analysis of layers taken at varying depths in these Heldre Hill soils on the Silurian formation at an altitude of 1,000 ft. gave:

Depth	*Coarse sand*	*Fine sand*	*Silt*	*Clay*	*Loss on ignition*
0–9 in.	..	25·0	30·5	24·5	17·2
9–18 in.	14·4	32·5	37·0	10·5	4·6
18–24 in.	8·8	33·8	35·0	13·8	7·0

The mechanical condition of the upper soil layer, due to its richness in organic matter, is satisfactory, whilst the sub-soil provides efficient drainage. Although the physical conditions are favourable for growth, these soils are very deficient in lime and phosphate. The calcium has been continually leached from the upper layers without any recovery through the agency of the grazing animal, as occurs on other upland soils providing moderate 'keep' and not completely dominated by bracken; hence there is no exchangeable calcium and the pH is as low as 3·9. They also contain a very low percentage of available phosphate,

but the available potash is well above the average for other soils in the area.

Calcium as a Nutrient for the Potato

In 1941 an experiment was laid out on Heldre Hill, Montgomeryshire, in order to ascertain the importance of calcium as a nutrient for the potato on this kind of land. In 1942 a similar experiment was carried out on a different portion of the same hill. The experimental plots were randomized; each plot consisted of 4 rows in 1941, and 5 rows in 1942, each row being 16 yds. long. Plants were obtained for analysis by sampling at equal intervals in the rows of plots to which ground limestone had been applied, and at the same intervals in the rows of the plots from which calcium had been entirely withheld.

The results obtained on these bracken areas have brought to light the paramount importance of calcium as a direct nutrient for normal development of the haulms. That the effect of calcium on potatoes in this particular type of soil is primarily a direct nutritional effect is shown in Table 1.

TABLE 1. *Composition of Potato Haulms grown on Bracken Area without and with Calcium (sampled 64 days after planting)*

	Without calcium		*With calcium* (Ground Limestone)	
	Stem	*Leaf*	*Stem*	*Leaf*
Nitrogen . . .	4·18	5·84	4·18	6·18
Phosphoric acid (P_2O_5) .	0·55	0·66	0·67	0·95
Lime (CaO) . . .	0·43	0·29	1·53	1·22

This table shows the exceptionally low calcium-content of the stem and leaf where calcium carbonate was not applied, and the four-fold increase in concentration of calcium following its application. It is evident that in the absence of limestone the nutritional needs of the vegetative parts of the plants for calcium were lacking, so that growth and development were greatly retarded. This is shown by the following mean weights and heights of the plants whose composition is given in Table 1:

	Weight	*Height*
Without calcium . .	18·6 gm.	8·7 in.
With calcium . . .	49·5 gm.	14·2 in.

Whereas the primary function of the ground limestone has been to supply the direct nutritional need for calcium, Table 1 indicates that it also had other functions. Simultaneously with the large increase in concentration of lime there has been a smaller but appreciable increase in concentration of phosphoric acid in both stem and leaf. To accomplish this the calcium carbonate must either have rendered the soil phosphate more available or increased the capacity of the plant for assimilating phosphate.

Effect of Ground Limestone on Yield of Tubers

Table 2 shows the effect of ground limestone (1 ton per acre) without and with other manures on the yield of potatoes in these bracken areas. The figures give the average yields obtained from duplicate plots in 1941 and 1942. Calcium being such an important factor, the equivalent of the calcium oxide supplied in the different manures is given as well as the other manurial constituents present.

TABLE 2. *Effect of Limestone without and with Other Manures on the Yield of Potatoes*

Series	Manures applied	Manurial constituents supplied (lb. per acre)				Yield (tons per acre)			
						1941		1942	
		CaO	N	P_2O_5	K_2O	No G/L[1]	G/L	No G/L	G/L
1	Nil	..	..	..	..	2·03	6·42	0·57	1·30
2	Sulph. Amm.	..	78	..	..	..	..	0·34	0·82
3	Superphosphate	120	..	78	..	..	..	4·76	6·18
4	Sulph. Amm., and 'Super'	120	78	78	..	6·00	11·82	4·03	6·85
5	Sulph. Amm., 'Super', and Pot. Muriate	120	78	78	56	..	..	3·65	8·04
6	Sulph. Amm., 'Super', and 'Potato Fertilizer'[2]	60	78	78	28	5·04	12·18	..	..
7	'Potato Fertilizer' only	..	78	78	56	2·88	13·89	2·30	7·45

[1] G/L = ground limestone at 1 ton per acre.
[2] The potato fertilizer contained ammonium phosphate and sulphate of potash.

The above table shows that the various treatments supplied different amounts of calcium and potash, but that where nitrogen and phosphate were applied, these were given at a uniform rate though not in the same state of combination. Where no ground limestone was applied, the calcium in the manurial dressing has produced an important effect on yield. Thus in 1941 the highest yields from the no-limestone plots were obtained from Series 4 and 6 where calcium had been supplied (as superphosphate), whilst the lowest yields were from Series 1 and 7 receiving no calcium. Similar results were obtained in 1942, indicating the important function of the calcium of superphosphate under these soil conditions.

Where calcium was applied as ground limestone, the calcium of the manures ceases to be a factor affecting yield. This is seen from the 1941 results where the highest yield is given by Series 7, although the manures themselves supplied no calcium. Where limestone has been provided, the effect of phosphatic manure is very marked, and brings to light the poverty of these soils in phosphate as well as calcium. The influence of nitrogen as sulphate of ammonia is principally dependent on whether the main needs of the potato for calcium and phosphate have also been satisfied. Where these have not been met, the effect of the nitrogen is to depress the yield, but where adequate quantities of these nutrients are present, the nitrogen produces a slight improvement.

The addition of manures to the limestone plots was followed by an increased yield in all series where phosphate was included, the greatest increases following complete dressings of nitrogen, phosphate, and potash.

To obtain an adequate response from manures on these soils calcium must also be applied: in the absence of limestone the yield from a complete potato fertilizer, such as ammonium phosphate and sulphate of potash, differs little from that of the untreated plots. This fertilizer failed because it contained no calcium. Where calcium is applied as ground limestone, the response compares favourably with that from any other complete dressings.

Table 3 shows that the limestone also produced an important effect on the size of the potatoes.

TABLE 3. *Effect of Limestone without and with Manures on the Percentage of Ware Potatoes*

		Percentage ware potatoes (by weight)			
		1941		*1942*	
Series	*Manures applied*	*No G/L*	*G/L*	*No G/L*	*G/L*
1	Nil	40	66	34	33
2	Sulph. Amm.	..	..	10	10
3	Superphosphate	..	..	64	76
4	Sulph. Amm. and 'Super'	63	78	69	80
5	Sulph. Amm., 'Super', and Pot. Muriate	50	78	63	85
6	Sulph. Amm., 'Super', and Potato Fertilizer	62	75	..	..
7	Potato Fertilizer only	43	79	57	83

The limestone has produced a marked increase in the percentage of ware potatoes in all series apart from 1 and 2 in 1942 where it was exceptionally low both without and with limestone.

Composition of Potatoes from Bracken Land

In both seasons the potatoes from the plots were sampled for analysis by taking an equal number at random from each bucket-full in a plot to give a total sample of 6 lb. per plot. The results based on dry matter are shown in Table 4.

Potatoes grown on the adjacent lowlands in the above two years were found to have an average percentage of 22·36 dry matter containing silica-free ash 4·1, nitrogen 1·35, phosphoric acid 0·72, and lime 0·12 per cent. respectively. It will be noted that compared with these the potatoes grown on the bracken area are generally lower in dry matter, ash, and phosphoric acid, but are higher in nitrogen. The lower dry matter coupled with the higher nitrogen point to a less mature condition in the bracken-area potatoes, and the climatic conditions at the higher elevations would undoubtedly be less favourable than in the lowlands for the crop to reach full maturity. In contrast to its effect on the haulms, the ground limestone had very little influence on the chemical

composition of the harvested tubers, and the small differences produced were largely dependent on the nature of the other fertilizers used in conjunction with it. In Series 7 receiving ammonium phosphate, the ground limestone, though greatly increasing the yield (Table 2), has depressed the dry-matter content. On the other hand, in Series 4 and 5 receiving superphosphate, the ground limestone has increased the dry-

TABLE 4. *Chemical Composition of Potatoes from Bracken Area (per cent.)*

1. Arran Banner (1941)

Series	*Manures*	*Dry matter*	*Ash*	*Silica-free ash*	*Nitrogen*	*Phosphoric acid* (P_2O_5)	*Lime* (CaO)
1	Nil	19·55	4·31	4·02	1·56	0·24	0·08
1*a*	Limestone	20·60	4·23	4·13	1·88	0·32	0·15
4	Sulph. Amm. and 'Super'	20·66	2·85	2·65	1·91	0·28	0·07
4*a*	Sulph. Amm., 'Super', and Limestone	21·26	3·02	2·79	1·51	0·26	0·09
7	Amm. Phos. and Pot. Sulph.	19·52	3·42	3·38	1·83	0·28	0·09
7*a*	Amm. Phos., Pot. Sulph., and Limestone	18·80	3·01	2·71	1·62	0·24	0·11
	2. Kerr's Pink (1942)						
1	Nil	20·44	4·90	4·63	1·67	0·28	0·11
1*a*	Limestone	20·37	5·13	4·63	1·62	0·28	0·10
4	Sulph. Amm. and 'Super'	22·20	2·69	2·35	1·78	0·42	0·09
4*a*	Amm. Sulph., 'Super', and Limestone	22·70	3·13	3·04	1·75	0·41	0·08
5	Sulph. Amm., 'Super', and Pot. Muriate	21·76	3·84	3·72	1·57	0·48	0·17
5*a*	Sulph. Amm., 'Super', Pot. Muriate, and Limestone	22·91	4·02	3·69	1·46	0·50	0·24
7	Amm. Phos. and Pot. Sulph.	20·95	3·89	3·79	1·62	0·25	0·06
7*a*	Amm. Phos., Pot. Sulph., and Limestone	18·91	4·18	3·93	1·82	0·74	0·16

matter content but at the same time somewhat diminished the nitrogen. Judged from the dry-matter content and the nitrogen of the tubers, it is evident that superphosphate either with or without limestone has yielded more mature tubers than ammonium phosphate. This may possibly be due to a more rapid fixation in these bracken soils of the phosphate from ammonium phosphate than that from superphosphate, the latter fertilizer having consequently a greater influence on the plant in its later developments. The greatest effect of all on the maturity of the tubers has been produced by the application of limestone followed by a mixture of sulphate of ammonia, superphosphate, and muriate of potash (Series 5).

Quality of Potatoes from Bracken Land

Quality in the potato is becoming of increasing importance in view of the developments in the processing of surplus stocks, when a potato that does not blacken after boiling is needed. The nature of the soil is

an important factor in this connexion, and the quality of potatoes from these bracken areas is of special interest seeing that potatoes have not until recently been raised on any extensive scale from this kind of land. The following observations on quality refer to the potatoes derived from bracken land to which ground limestone had been applied at the rate of 1 ton per acre, the potatoes from the unlimed areas being too low in yield and too small in size to have any economic value. For observing quality the produce from different plots was stored until the end of January, then boiled, and the behaviour noted on exposure to the air.

In none of these tests did typical blackening occur although in some of the plots the tubers were discoloured. Arran Banner potatoes grown in 1941 were generally of a good colour with floury texture. The best quality potato was obtained from plots receiving nitrogen and phosphate (Series 4*a*), the least satisfactory from plots receiving a heavy dressing of a complete fertilizer (double the dressing of Series 7*a*). Potatoes receiving no manure apart from ground limestone (Series 1*a*) were satisfactory in all respects, and equalled in quality those receiving a moderate dressing of a potato fertilizer (Series 7*a*).

With Up-to-Date, also grown in 1941, a potato of good colour, close texture, and very full flavour was obtained. The best potatoes were from plots receiving no manure apart from ground limestone (Series 1*a*). Potatoes showing a tendency to discoloration were obtained from plots receiving nitrogen and phosphate (Series 4*a*). Discoloration did not occur in the tubers from plots receiving complete fertilizer (Series 5*a*), but the flavour was not as full as in those supplied only with ground limestone (Series 1*a*).

The differences between the produce of the various plots of Kerr's Pink grown in 1942 were very small, there being no appreciable discoloration from any of the potatoes on exposure after boiling. The best potato for texture, colour, and flavour was grown on plots receiving nitrogen and phosphate with a low ratio of nitrogen to phosphate (half the nitrogen of Series 4*a*).

In Doon Star grown in the same season, more discoloration was obtained than with any of the other three varieties; it was most marked where a complete fertilizer of high nitrogen ratio had been applied (Series 5*a*), and where nitrogen and phosphate were applied without potash (Series 4*a*). Little discoloration was developed from the produce of control plots receiving limestone only (Series 1*a*), and it was also slight where a complete fertilizer of low nitrogen ratio had been applied (half the nitrogen of Series 5*a*).

It is therefore evident, in spite of their intense acidity and poverty in lime and phosphate, that, with suitable manuring, these bracken areas can yield potatoes of very satisfactory quality. The main factor determining quality on these soils is the variety grown, and further experience is needed to decide on the best varieties for the area. Apart from the paramount importance of calcium, the main condition to ensure quality, in so far as manuring is concerned, is the maintenance of a reasonable balance between the different constituents of the fertilizers applied, and in particular, the avoidance of a high nitrogen ratio. For

certain varieties the addition of potash seems to be of significance in ensuring high quality.

Summary and Conclusions

Although the potato is a crop that thrives under very acidic soil conditions, bracken areas on the Welsh uplands have been so completely depleted of their exchangeable calcium that successful growth is impossible without the application of calcium in some form or other. It is shown that the effect of calcium applied as ground limestone is primarily a direct nutritional one. In the untreated soil the stunted haulms show an exceptionally low calcium-content, whilst a four-fold increase in both stem and leaf follows the application of ground limestone.

Accompanying the increase in lime-content, there has been a smaller but appreciable increase in concentration of phosphoric acid in the stem and leaf of the haulms, a result that may be due to the calcium carbonate having rendered the soil phosphate more accessible to the plant through its influence on the soil, the plant, or on both. Where fertilizers are applied to these bracken areas in the absence of ground limestone, they have little if any effect on the yield of tubers, unless the element calcium is a constituent of them, but mixtures supplying the plant with calcium have a very appreciable effect.

Where ground limestone is applied to the soil it not only greatly increases the yield following the application of various fertilizers, but greatly increases the proportion of ware tubers.

The manurial constituent having the greatest effect on yield in the presence of ground limestone is phosphate. Both nitrogen and potash effect a further improvement in yield where adequate quantities of limestone and phosphate have been included.

Potatoes grown on the bracken areas contain less dry matter but more nitrogen than those grown on the adjacent lowlands, the climatic conditions on these higher elevations being less favourable in promoting maturity. The greatest effect on the maturity of the tubers has been produced by the application of limestone followed by a complete fertilizer consisting of sulphate of ammonia, superphosphate, and muriate of potash.

It is shown that with suitable manuring the bracken areas can produce potatoes of a very satisfactory quality, and that apart from the importance of calcium, the main condition to ensure quality, in so far as manuring is concerned, is the maintenance of a reasonable balance between the different constituents of the fertilizers, in particular, the avoidance of a high nitrogen ratio.

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THE PUSA WHEATS: THE WHEAT-BREEDING WORK OF THE IMPERIAL AGRICULTURAL RESEARCH INSTITUTE

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Introduction.—India was a great producer of wheat long before the famous wheat-growing areas of the United States, Canada, and Australia were developed or even discovered, and archaeological investigations at Mohenjo-daro [1] have shown that wheat of a cultivated species was being grown about 5,000 years ago. Luthra [2], from an examination of the carbonized grains found in this ancient site, concluded that they belonged to the two species *Triticum vulgare* Host and *T. compactum* Host, but judging from samples from the same site which were examined by the writer, there is little doubt that they must be referred to the endemic species, *T. sphaerococcum* Perc., which is still grown in certain parts of India. Marshall [1] does not mention the finding of grains of *T. vulgare*, and the writer also did not find any in the samples which were made available to him.

Wheat occupies, on an average, about 33 million acres of land and is the staple food of a large section of the population of the Indian subcontinent. It was natural therefore that this pre-eminent food plant should receive special attention at the Imperial Agricultural Research Institute, Pusa (now transferred to New Delhi), when work on the amelioration of Indian crop plants was begun there in 1905. The purpose of the present paper is to give a brief account of the investigations conducted at the Institute, and their results, but before doing so it is desirable to refer, very briefly, to a few special features of the wheat crop in India that must be borne in mind when discussing wheat improvement in this country.

Perhaps the most striking feature is the short period, ranging from about the end of October to the end of March, within which, owing to limitations imposed by climate, particularly temperature, the crop must grow and mature its grain; this means, in effect, that only early-ripening forms of wheat can be raised, and, as a matter of fact, all Indian wheats correspond in their general character to the spring wheats of Europe and America, although they are actually grown as a cold-weather crop throughout India. As early wheats inherently tend to be lower-yielding than varieties which occupy the ground for a longer time, the restricted period of growth available to the crop sets a limit to the betterment of Indian varieties in regard to yield. It must, however, be remembered that much of the area over which wheat is cultivated in India is two-crop land, and sometimes the cereal is sown in admixture with Brassica and other crops; often no cognizance is taken of these facts when wheat production per acre is compared, to its disadvantage, with that in foreign countries where generally only one crop a year is taken.

Another factor of importance is the supply of water, and wheat in

India can be broadly divided into two groups, irrigated and non-irrigated, the area under the latter being by far the greater. As would be expected, higher out-turns are obtained with irrigation, the difference being accentuated in seasons of deficient rainfall; but wheat grown without irrigation is generally of superior quality. In the non-irrigated areas of central and peninsular India, durum wheats predominate.

Unlike the case in western Europe and America, bearded varieties are preferred, as there is a belief, fostered by the agricultural departments, that these are less liable to the depredations of birds, and even wild beasts, than the awnless ones.

Five species of wheat occur in India, namely, *T. vulgare*, *T. sphaerococcum*, *T. durum* Desf., *T. dicoccum* Schübl., and *T. turgidum* L. The first two are members of the bread-wheat group with $2n = 42$ chromosomes, and the remaining three belong to the emmer group with $2n = 28$ chromosomes. Howard and Howard [3] stated that dwarf wheats belonging to *T. compactum* are found in the south-west of the Punjab and, to a smaller extent, in the Central Provinces and the United Provinces. Percival [4], however, believes that these club wheats referred to by the Howards belong to *T. sphaerococcum*, and that *T. compactum* is not found in India, a conclusion that has been confirmed by subsequent research [5]. Commercially, only *T. vulgare* and *T. durum* are of real importance, especially the former which is dominant in the great wheat area of northern India. The wheat-improvement work of the Institute has been limited to this species.

Earlier Investigations

Wheat breeding.—The earliest phase of the wheat investigations was the survey and collection of the existing wheats, an undertaking which resulted in the accumulation of much useful information and revealed the richness of the indigenous material [3, 6, 7, 8]. Side by side with the surveys, the breeding of improved varieties was taken up. This work, which was initiated and carried out by the Howards, assisted by A. R. Khan, led to early success in the selection from indigenous forms of the famous Pusa 4 and Pusa 12[1] wheats. Pusa 4 is an early, awnless, white-chaffed, fairly rust-resistant wheat of good standing power which has good adaptability and has given excellent results over a wide range of conditions in India; it is also grown in Australia, and to a less extent in Africa, where its large, fine-quality high-protein grain is much appreciated. Pusa 4 has won numerous first prizes in grain exhibitions both in India and abroad. Though newer strains have since been bred and distributed, Pusa 4 is firmly established in popular favour in large tracts in the north Indian plain and in the irrigated areas of the Bombay Presidency; and the demand for its seed is large and constant.

Pusa 12 was evolved, like Pusa 4, by selection from indigenous

[1] Since the transfer of the Imperial Agricultural Research Institute from Pusa to New Delhi in 1936 the wheats produced by the Institute are known as Imperial Pusa wheats to distinguish them from any strains that might be subsequently bred by the provincial department of agriculture at Pusa.

material. It is a very high-yielding, awnless, red-chaffed wheat particularly suited to certain parts of the United Provinces, where it is still the dominant variety. It is slightly later than Pusa 4, with longer but weaker straw, and is rather inferior to it in rust-resistance, although it is better in this respect than the local unimproved varieties. The grain is longer and softer than in the other Pusa wheats and is much liked for *chapatti*-making.

In the earlier work at the Institute, in which emphasis was laid on yield and quality of grain, Indian wheat had a poor reputation abroad because the wheat exported from Karachi mainly comprised a mixture of soft white sorts, poor for bread-making and deficient in flavour. As a matter of fact, India, owing to the great age of her agriculture, is specially rich in varieties, and many qualities of grain are available. In the case of the hard wheats, the conditions of rapid ripening, the soil, and the dry climate all further the inherent quality in producing a hard vitreous grain of high protein-content and high quality for bread-making, and probably few wheats in the world can equal the handsome appearance of some of the large-grained, translucent, amber-coloured Indian varieties. A series of experiments carried out by the Howards with the co-operation of H. M. Leake and A. E. Humphries and, later, by F. J. F. Shaw with the co-operation of E. A. Fisher [9, 10, 11, 12, 13, 14, 15] demonstrated conclusively that there exist Indian wheats which are equal in quality to good Manitoba wheat. In the breeding of the Pusa wheats the aim has been to produce strong wheats with high protein-content, not only because of the requirements of the export trade (this, however, has practically ceased since the War of 1914–18), but because experience showed that such wheats were also the best for making *chapattis*, the form in which wheat is mainly consumed in India.

Hybridization was resorted to at an early stage of the investigations, but since crosses between Indian and foreign wheats could not be produced at Pusa, where the latter class of wheats does not flower in time for crossing and for the resulting grain to ripen before the hot weather sets in, the Indian varieties to be used as parents were sent to Cambridge in 1910 for spring sowing, and crosses were made there between the Indian types and America Club and other wheats. The F1 and subsequent generations were grown in India. Much was expected from this series of crosses, but unfortunately the hopes entertained were not fulfilled. Better results were obtained when crosses were made among the Indian wheats themselves. From these a number of successful wheats were bred, outstanding among which is Pusa 52.

Pusa 52 was produced by hybridization between Punjab 9 and Pusa 6 wheats, and associates the high-yielding capacity and bearded nature of the former with the good grain-quality of the other parent. The straw stands quite well and the wheat is a very heavy yielder. It has now become the principal wheat of the important wheat-growing province of Bihar and of the adjoining areas of the eastern United Provinces and western Bengal.

Two other wheats, Pusa 80–5 and Pusa 101, which were produced by

hybridization at about this time, have now become established. The former is a hybrid between Pusa 4 and Pusa 6 and resembles the former in many ways. It has proved particularly suitable for the hills of the Punjab. Pusa 101 (Muzaffarnagar × Pusa 22) is an outstandingly early wheat and is one of the few wheats bred in northern India which has had a measure of success in the black cotton soils of the Central Provinces. In northern India its distribution has been discontinued because of its susceptibility to rust and smut.

An important addition to the Pusa wheats was made in 1927–8 when Pusa 111 was selected from a natural cross in Pusa 4, which it resembles very closely. It is, however, easily distinguished from Pusa 4 by its glabrous glumes, those of Pusa 4 being felted; this character is of some moment because in the moister wheat-growing areas the hairs condense dew and so add to the weight of the ear and increase the tendency to lodge; further, the felted glumes hold moisture in damp weather and favour the incidence of rust in the ear. The grain of Pusa 111 is of superlative milling and baking quality.

Almost at the same time a natural cross was observed in a plot of the well-known Australian variety Federation, and from this the black-awned, small-grained Pusa 114 was selected. The outstanding feature of this wheat is its immunity to loose smut [16]. It also possesses some adult resistance to black rust and has been appreciated in Sind for this reason. Agronomically, however, it has the defect, serious in India where wheat is harvested only after it is dead-ripe, that the glumes do not hold the grains firmly after they have ripened, so that some loss of grain occurs in the processes of harvesting, especially in the drier tracts.

In 1925, Pusa 4 and Pusa 52 were crossed with Federation wheat with the object of improving the standing power of the straw of these agriculturally important varieties, and also to obtain greater disease-resistance if possible. From the cross with Pusa 4 the new variety Pusa 165 was evolved, and from the other cross, Pusa 120 and Pusa 125. Pusa 165 is a large-grained, beardless wheat that has proved a consistently high yielder in the great wheat area of northern India. Although the straw is not thick, it has remarkable standing capacity. The grain is perhaps the most attractive in the whole of the Pusa series of wheats, and the variety possesses considerable field resistance to the rusts, to loose smut, and to a lesser extent to flag smut.

Both Pusa 120 and Pusa 125 are stiff-strawed, bearded, and of satisfactory grain-quality. Agronomically, Pusa 125 is superior to Pusa 120 (which suffers from the defect of grain-shedding) and is one of the highest-yielding wheats produced in India. Pusa 120, however, is outstandingly rust-resistant, particularly to yellow rust [17], and also to loose smut [16], and in view of these valuable qualities an attempt has been made in recent years to select out a non-shedding form of it. Non-shedding variants were easily secured, but on re-testing it was found that all of them, except one, had lost the resistance to yellow rust which constituted one of the most important characters of Pusa 120. The single non-shedding variant which has maintained its rust-resistance (and also smut-resistance) is considered promising and is undergoing

yield trials in comparison with Pusa 120 and other wheats. The bread-making quality of Pusa 120 and Pusa 165 has been described by Pal [18]. Altogether, Pusa 120 must be considered one of the most useful wheats at present available in India for breeding work.

No mention has been made, in this brief account, of varieties like Pusa 54 and Pusa 100 which had a considerable but ephemeral success. Information regarding these is given in the annual reports of the Imperial Economic Botanist, and in the series of papers on the milling and baking qualities of Indian wheats, already referred to.

Taking the wheats which bear the Pusa name as a group, they have certain characteristics in common. They are good yielders (they have given yields of more than 40 mds. (3,280 lb.) per acre under conditions of good cultivation), give grain of excellent quality, have fair to good standing-power, and are more disease-resistant than the local unselected wheats. For these reasons not only are they widely cultivated in India, but they have also been utilized for breeding work in many countries. Although stress was laid from the very beginning on disease-resistance, much could not be done in the direction of deliberate, planned breeding for disease-resistance until further advances in the aetiology and epidemiology of Indian wheat diseases made reliable, artificially controlled tests for disease-reaction possible. In the case of the rust diseases, the earlier work was perforce carried out in ignorance of the physiologic races occurring in India, and there was no means of discriminating between true resistance and 'escapes' due to lack of inoculum of the parasite or other causes. Thus 6 varieties found in Bihar and considered to be immune or highly resistant to the 3 rusts [19] were found later to have been prematurely so proclaimed, for subsequent testing under controlled conditions showed them to be highly susceptible.

Genetical studies.—The genetics of some characters was studied by the Howards [20, 21], and the results are summarized on the next page. These results are in general agreement with those obtained by workers in other parts of the world.

The Present Investigations

The present phase commenced in 1934, when the writer took over charge of the wheat work. The work already carried out (by the Howards until 1924 and by Shaw until 1934) has resulted, as already described, in the production of high-yielding varieties possessing excellent quality of grain. It was, however, apparent that considerable scope existed for improvement in other respects, and there was a compelling need for varieties resistant to the maladies which inflict such heavy losses from year to year. Although, fortunately, there is no serious insect pest of wheat in India, in the main wheat-growing areas (with the exception of termites which are often troublesome in the early stages of the crop) the fungous diseases are exceedingly important, especially the rusts and smuts.

It was realized that, in this and other respects also, the further improvement of Indian wheat would be an arduous task for which careful planning was necessary, bearing in mind the desired characters of straw,

Character studied	*Dominance*	*Ratios obtained in F2*	*No. of factors identified*
Grain colour (red × white)	F1 intermediate	3 red : 1 white 15 red shades : 1 white 63 ,, ,, : 1 white	One, two, or three independent factors
Grain texture (soft × translucent)	F1 intermediate	1 soft : 2 semi-translucent : 1 translucent	One
Glume colour (red × white)	F1 intermediate	3 red : 1 white	One
Glume felting (felted × smooth)	F1 intermediate	3 felted : 1 smooth 15 various grades of felting : 1 smooth	One (in wheats with one kind of hair only) Two (in wheats with two kinds of hair, short and long)
Presence or absence of awns:			
(1) Bearded × short-tipped	F1 half-bearded	1 bearded : 2 half-bearded : 1 tipped	One
(2) Bearded × beardless	F1 short-tipped	15 various bearded types : 1 beardless	Two
Colour of awns (black × white)	black dominant	3 black : 1 white	One
Shattering of ears (shattering × non-shattering)	..	15 shattering : 1 non-shattering	Two

ear, and grain, besides resistance to diseases and to adverse conditions of growth; the co-operation of the plant pathologist and the plant chemist was also essential. For when plant-breeding is first begun in a country in which hitherto such work has not been attempted, it is often possible to secure substantial increases in yield of 50 per cent. or even more by simple selection; but after work has been in progress for some time and good varieties have been secured, it becomes increasingly difficult to obtain further large increases and the breeder has to be content with smaller, but harder-won, accomplishments. There is, moreover, a tendency to judge current results in plant-breeding by previous achievements in variety improvement, and it will take time before it is recognized that the era of the old general-purpose variety is ending, and that the newer varieties will be bred to suit the special requirements of particular areas and will require intelligent handling to secure the best results.

To ensure that the Pusa wheats of the future shall be real advancements on their famous predecessors, the breeding work has been reorganized on a wider basis than hitherto, and attention has also been paid to such topics as vernalization, which are connected with wheat breeding only indirectly. The main lines along which work is progressing at the Institute are described below.

Living collections.—Modern plant-breeding is synthetic, i.e. parents are chosen and their hybrid segregates selected on the basis of specifically

valuable features. The knowledge of varieties and plant characteristics of whatever kind, of which relative yields of old and new varieties are reflections, is therefore of great value. As the old wheat collections had been almost entirely lost, the first task was to obtain the material for research from widely differing localities; this was taken up, and the section now possesses a collection of about 1,500 varieties from different parts of India, about 900 exotic varieties including important material from Afghanistan and Persia collected by various expeditions to these countries, a full collection of the wheat species, and a number of grasses belonging to genera allied to Triticum, such as Aegilops, Agropyron, &c. The maintenance of these living collections has been facilitated by the establishment in 1935 of a substation at Simla[1] for wheat and potato research. The substation has also made it possible to effect crosses between early-maturing Indian wheats and even the latest-ripening imported wheats, and in 1935 alone over 100 such crosses were successfully accomplished.

Breeding for rust-resistance.—In India all the three wheat rusts, namely black, brown, and yellow, caused respectively by *Puccinia graminis tritici* Eriks. and Henn., *P. triticina* Eriks., and *P. glumarum* (Schm.) Eriks. and Henn., ravage the wheat crop, and according to an estimate made about 40 years ago [22] the annual loss to the country from this cause is not less than Rs. 40,000,000.

Mehta [23] has shown that, in the heat-soaked plains of India, the rust spores are killed out during summer, and the wheat crop is infected afresh each year by spores wafted down by currents of air from the Himalayas and other mountains, where wheat is grown up to an altitude of about 9,000 ft. above sea-level. If, therefore, none but rust-resistant wheat were to be grown in the hills, the chances of infection in the plains would be reduced, apart from the value of such wheats to the hill farmers themselves. This reasoning induced the Imperial Council of Agricultural Research, which finances the wheat-breeding investigations at the Simla substation, to limit the scope of the work to apply only to the hill regions, where the area under wheat cultivation is relatively very small, constituting less than 5 per cent. of the total. It is obvious that the former object could be achieved only if barley and any other alternate hosts of the wheat rusts are also taken into account as possible sources of infection: this matter is under consideration and the breeding of rust-resistant barleys is likely to be taken up soon.

The attempt to breed wheats resistant to all the three rusts is ambitious and could not have been contemplated with any considerable degree of confidence a few years ago. With the recent advances in the knowledge of the mode of inheritance of resistance to the rusts [24, 25] new confidence arises and the difficulties in the way of realization of such an ideal do not appear to be insuperable. An encouraging feature is the fact that the number of physiologic races of the rusts found in India is comparatively very small, investigations over a large number of years by Mehta [23] having revealed only 6 races of black rust, 6 races of brown rust, and 8 races of yellow rust. Mehta is further of opinion that, as in

[1] The substation is financed by the Imperial Council of Agricultural Research.

Australia, the formation of new races of black rust, as a result of hybridization on barberries, occurs very rarely in this country if at all.

In view of the complexity of the problem, the work, which is being done in collaboration with K. C. Mehta, was taken up in two stages, the first being the breeding of varieties resistant to the black, brown, and yellow rusts respectively, and the second the synthesis of further varieties embracing resistance to all the three rusts simultaneously. Preliminary tests showed that none of the indigenous varieties tested possessed much resistance to any of the rusts, with the exception of Pusa 120, which was very highly resistant to yellow rust; on the other hand, a few exotic varieties were virtually immune to all the Indian physiologic races of one or other of the three rusts, but, owing to their late maturity and other reasons, these were unsuited for direct cultivation under Indian conditions. Hybridization was therefore adopted. Resistance was found to be dominant in some cases and susceptibility in others. The segregating progenies were tested in both the seedling stage in the glasshouse and the adult stage in the field, where epiphytotics of rust were artificially created; selections were made year after year of plants combining a high degree of rust-resistance with the desired characters of grain, ear, and straw. At the time of writing, the first stage of the breeding work is nearing completion. Varieties respectively resistant to all the races of yellow and brown rust known to occur in India have been built up, and varieties resistant to all the Indian races of black rust too are expected to be obtained shortly.

Progress against black rust has been relatively slower, because, at the time work was started, no variety of *T. vulgare*, indigenous or imported, resistant to all the Indian races of this rust was known. The only wheat then known to possess high resistance to these races was the *dicoccum* variety, Khapli. Unfortunately crosses between this and *vulgare* varieties either failed or gave rise, with dismal constancy, to sterile hybrids only. In one cross alone, Reliance × Khapli, an F1 plant set grains, and even here only 2 grains were obtained; these gave rise to plants of the Khapli type, and subsequent progenies behaved similarly. Owing to this difficulty, an extensive search was instituted for *vulgare* varieties resistant to black rust, and a large number of Indian and foreign varieties was tested. The search was rewarded by the discovery of a Kenya wheat (to which the accession number E 144 has been given) possessing a satisfactory degree of black-rust resistance [26]. A little later yet another wheat from Kenya (E 220) has been found highly resistant to the races of black rust existing in India.

The stage is therefore set for the second and more arduous phase of the problem: the synthesis of varieties highly resistant to all the three rusts. A double cross has been planned which, if unforeseen difficulties do not arise, will, it is hoped, result in the production of varieties possessing the desired combinations of characters.

Breeding for smut-resistance.—Next to the rusts, the most serious disease of wheat in India is loose smut, caused by *Ustilago tritici* (Pers.) Jensen. Although in the absence of accurate disease-surveys the losses occasioned by smut attack cannot be reliably assessed, there is no

question that loose smut causes much damage in certain years, especially in the Punjab, Sind, and the United Provinces. Tests to discover the resistance or susceptibility of the wheat strains bred at the Imperial Agricultural Research Institute, and also of other wheat varieties which might be useful for breeding work, were begun in 1936 by B. B. Mundkur in the Mycology Section [27]. The results of tests with nearly 100 varieties have been published [16] and should be of value to wheat-breeders throughout India; a few varieties including Pusa 114 were found to be immune, whilst certain others including Pusa 120 and Pusa 165 were resistant. The varieties just named are derived, by crossing, from the Australian variety Federation, which itself has proved to be immune in these tests; evidently genetic factors for high resistance to loose smut have been transmitted to these varieties from the Federation parent. It was interesting to note that the results from these tests carried out under strictly controlled conditions agree with field experience of the varieties concerned wherever data are available for comparison.

Unlike the position with regard to the rusts, we are therefore in the fortunate position of having several good wheats which possess high resistance amounting to virtual immunity in a few cases. At the same time some of the most important commercial wheats including Pusa 4, Pusa 12, Pusa 52, the Punjab strains C518 and C591, and the United Provinces strain, Cawnpore 13, are highly susceptible, and further breeding work is necessary. Some of the hybrids bred for rust-resistance (*v.s.*) are now being tested for their resistance to loose smut and flag smut, and if any are found to possess high resistance the production of strains resistant to both rust and smut diseases will be facilitated.

Attempts to select out resistant sub-strains within some of the partially susceptible varieties were successful in several instances, showing that varieties which are apparently homozygous for morphological characters are not necessarily pure for disease-resistance. For instance, Pusa 120 showed 9·7 per cent. susceptibility in the first year's tests, but the seed that had been 'screened' or 'sieved' by subsequent selection gave rise to immune plants only, in later years [16].

Another disease of wheat sometimes important in the Punjab, the NW. Frontier Province, and Baluchistan, is flag smut, caused by *Urocystis tritici* Koernicke. The resistance of a large number of varieties to this fungus has been tested [16]. Some varieties, including Pusa 4, Pusa 80–5, and Pusa 111, were found to be highly or completely resistant; unfortunately, resistance is present, in most cases, in varieties which are susceptible to loose smut. An exception is Pusa 165, which is satisfactorily resistant to both.

Yet another disease of wheat, Karnal bunt, caused by *Neovossia indica* (Mitra) Mundkur, is important in some years in north-western India, and, in fact, is more serious than flag smut. For a long time the mode of infection by this disease remained obscure, but very recently Mundkur [28] has solved the mystery, and it is hoped that the testing of varieties for resistance to Karnal bunt will now be possible.

Genetical and cytological studies.—Recent advances in genetics and cytology, as a result of which light has been thrown on the causes of the

sterility which often attends wide crosses, will undoubtedly play an important role in the further realization of the plant-breeder's ideal of a wheat which will yield well, resist diseases and adverse conditions of growth, and produce grain of high nutritive value suitable for bread-making. Thus far only meagre use has been made of the less well-known wheat species, and of cereals and grasses of the genera allied to Triticum with which wheat can be induced, albeit with difficulty, to cross. Some of these are reputed to possess characters such as disease-resistance and drought-resistance which it is highly desirable to transfer to the common bread-wheat varieties. If such a transfer could be accomplished, not only would wheat-growing be freed to a considerable extent from the hazards which at present attend it, but it might make possible the commercial cultivation of wheat under conditions and in altitudes and latitudes where it has hitherto been impracticable. Hence the study of the less well-known wheat species and allied species of grasses forms an important part of the wheat work of the Institute.

Reference has already been made to certain crosses between *T. vulgare* and *T. dicoccum* (variety Khapli) which were made in connexion with the problem of breeding rust-resistant varieties of wheat. As soon as it became apparent that these crosses might not succeed, *T. dicoccum* was hybridized with *T. durum*; the latter species can be crossed with *T. vulgare* with greater ease than the former, and hence in this way the difficulty of transferring the rust-resistance of *T. dicoccum* to *T. vulgare* could be 'bridged'. As a result of this work, strains of *T. durum*, as resistant to India races of black rust as the Khapli parent itself, were produced, but these were not crossed with *T. vulgare* because by this time high resistance had been discovered in some Kenya varieties of the latter species.

In 1936–7 crosses were attempted between *T. Timopheevi* Zhuk. and *vulgare* varieties, but the seeds of these failed to germinate. Crosses between *T. Vavilovi* Jakubz. and *T. vulgare*, *T. dicoccum*, and between *T. dicoccum* and *T. persicum* Vav., gave, however, very vigorous hybrids. The species *T. Vavilovi* was selected for special study and the mode of inheritance of some characters in crosses between it and *T. vulgare* and *T. sphaerococcum* has been studied for the last four years. Subsequently to 1936–7, a very large number of crosses has been attempted, in numerous combinations among the species of *Triticum* themselves (including the wild species *T. aegilopoides* Bal., *T. dicoccoides* Korn., *T. Timopheevi*, and Kostoff's synthetic *T. Timococcum*), and between wheat and rye, barley, *Aegilops*, *Agropyron*, *Lolium*, &c. The cytogenetic study of the rich material became possible from 1938 when S. Ramanujam joined the Institute. The results of a preliminary study, carried out under his supervision, of the following hybrids have already been published: F1 *T. vulgare* × *T. Timopheevi*, F2 *T. vulgare* × *T. dicoccum*, [(*T. vulgare* × *T. dicoccum*) × *T. dicoccum*], [(*T. dicoccum* × *T. durum*) × *T. vulgare*], and *T. vulgare* × *Aegilops caudata* [29].

Recently the hybrids, some of them perennial, between wheat and species of couch-grass (Agropyron) produced by Tzitzin in Russia have attracted much attention. In the major wheat-growing area of India,

however, the question of perennial wheat does not arise, for, firstly, wheat cannot be expected to survive the scorching summer of these tracts, and secondly, on most of the land two (sometimes even three) crops a year are taken so that a perennial wheat crop would not fit into the existing system of rural economy. Apart from perennial habit, however, the grasses possess certain valuable characters which are attractive to the wheat breeder, and it is for this reason that the Institute has made a collection of grasses for study and hybridization, paying special attention to the indigenous forms.

Physiological studies.—Over the greater part of India wheat is not irrigated and the success of the crop is dependent upon the amount and the distribution of the light winter rains. The question of drought-resistance is therefore peculiarly important in India and there is a need of varieties which can give a good crop of ripe grain with a minimum quantity of water. Work has recently been started at the Institute to obtain more information regarding the complex of factors that make for drought-resistance, and, if possible, to find an index of drought-resistance which could be employed by the plant-breeder. As a first step, and in the absence of knowledge as to which of the extant varieties are drought-resistant, a collection of 260 varieties has been grown under 'dry' conditions at Delhi, and also at Karnal and Pusa, for the past three years, and observations have been taken on height of plant, tillering, yield, and other characters. From the data thus accumulated varieties will be tentatively classified as resistant or susceptible, and detailed investigation will then be undertaken with a view to correlating resistance to drought with easily determinable morphological or biochemical characters. Experiments are also in progress on the induction of drought-resistance by means of physical and chemical pretreatment of wheat seeds.

Investigations have been conducted, since 1938, on the vernalization of wheat. With English winter wheats the best results have been obtained by a combination of low-temperature and long-day treatment, and under such conditions the variety Cambridge Rivett, in one experiment, flowered 8 weeks earlier than the control. Indian varieties, however, appear to be indifferent to low-temperature treatment, but show earlier flowering when given long-day conditions [30].

Heterosis studies.—At the Institute a study of heterosis was taken up with special reference to the effect of such factors as different dates and times of sowing, different depths of sowing, and varied conditions of spacing [31]. The results showed that the manifestation of heterosis is greatly influenced by various external factors, thereby indicating the desirability of investigating hybrid vigour under as wide a range of conditions as possible.

Description of genetic variability and registration of wheat varieties.—The Imperial Council of Agricultural Research took up about 6 years ago the question of standardizing descriptions of the characters of crop plants in order to enable the range of variability present in various crop plants to be described in a uniform manner, using a standard nomenclature. As a result, committees were set up from time to time to deal

with the major crop plants of India, and standard schedules of descriptive terms have already been published for rice, cotton, jowar, and wheat. The schedule for wheat [32] was based on a note by the present writer, which itself was based on the experience garnered in the laboratories and experimental plots of the Institute in the course of handling large collections of indigenous and foreign varieties.

The Institute has also been entrusted with the registration of wheat varieties. For this purpose a register is maintained in which will be entered details of all commercial varieties grown in India and also those that are of plant-breeding interest. Detailed descriptions of these varieties will be published, using the standard schedule referred to above.

Miscellaneous studies.—As part of the study of genetic variability in wheat, a large collection of wheats is being grown simultaneously at New Delhi, Pusa, and Coimbatore; the behaviour of the varieties in respect of several characters is being studied under these very diverse environments.

Mixtures of exotic wheats, of inter-varietal hybrids, and even species are being grown, year after year, to see which types are favoured by the local environmental conditions. The study of the survivors may furnish a clue to the characters to which the breeder must pay particular attention when evolving new strains for such conditions.

As a study of plant-breeding technique a cross between a European and an Indian wheat has been treated in three ways since the F2 generation. On a portion of the material the ordinary method of single-plant selection has been followed, on another portion only bulk sowing without selection was done, whilst on the remaining portion a method intermediate between the two, in which a very large number of plants was selected and bulked, has been followed. Homozygous cultures have been obtained, and are now being compared with a view to determining which of the three techniques adopted was the most efficient.

Summary

In the introduction attention is drawn to some special features of the wheat crop in India. The wheat-breeding investigations at the Imperial Agricultural Research Institute are described. In the earlier stages of work emphasis was laid mainly on yield and quality of grain; the present investigations are focused on resistance to the major diseases of wheat in India, that is, the rusts and the smuts. Studies are also in progress which are designed to produce wheat strains of greater drought-resistance and more nutritive value. To attain these objectives cytogenetical and physiological investigations have been started. The possibility of using the less well-known wheat species, and grasses belonging to genera allied to *Triticum*, is being actively explored.

The outstanding Pusa wheats, resulting from the work of the Institute, are described briefly.

REFERENCES

1. J. MARSHALL, Mohenjo-daro and the Indus Civilization, 1931. Arthur Probsthain, London.
2. J. C. LUTHRA, Ancient Wheat and its Viability, Curr. Sci., 1936, **4**, 489–90.
3. A. HOWARD and G. L. C. HOWARD, Wheat in India, 1909. Thacker Spink, Calcutta.
4. J. PERCIVAL, The Wheat Plant, 1921. Duckworth, London.
5. B. P. PAL and B. B. MUNDKUR, Ind. J. Agric. Sci., 1941, **11**, 687–94.
6. A. HOWARD and G. L. C. HOWARD, Mem. Dept. Agric. India. Bot., 1909, **2**, 1–66.
7. G. L. C. HOWARD, ibid. 1916, **8**, 1–88.
8. A. HOWARD, G. L. C. HOWARD, and A. R. KHAN, ibid. 1915, **7**, 273–85.
9. A. HOWARD and G. L. C. HOWARD, Agric. Res. Inst. Pusa, 1908. Bull. No. 14.
10. —— —— ibid. 1910. Bull. No. 17.
11. —— —— ibid. 1911. Bull. No. 22.
12. A. HOWARD, H. M. LEAKE, and G. L. C. HOWARD, Mem. Dept. Agric. India. Bot., 1910, **3**, 191–220.
13. —— —— —— ibid. 1913, **5**, 49–102.
14. —— —— —— ibid. 1914, **6**, 233–66.
15. F. J. F. SHAW, Ind. J. Agric. Sci., 1931, **1**, 295–414.
16. B. B. MUNDKUR, Curr. Sci., 1943, **12**, 230–1.
17. F. J. F. SHAW and B. P. PAL, Agric. Live-stk. India, 1936, **6**, 202–3.
18. B. P. PAL, Ind. J. Agric. Sci., 1938, **8**, 153–60.
19. A. HOWARD, Some Possible Improvements in Canadian Wheat. Proc. World's Grain Exhib. Conf. Regina (1936), 1935, **2**, 50–1.
20. A. HOWARD and G. L. C. HOWARD, Mem. Dept. Agric. India. Bot., 1912, **5**, 1–47.
21. —— —— ibid. 1915, **7**, 273–85.
22. E. J. BUTLER, Dept. Agric. India, 1903. Bull. No. 1.
23. K. C. MEHTA, 1914. Sci. Monogr. I.C.A.R., No. 14.
24. B. P. PAL, Agric. Live-stk. India, 1935, **5**, 139–44.
25. E. R. AUSEMUS, Bot. Rev., 1943, **9**, 207–60.
26. K. C. MEHTA and B. P. PAL, Nature, 1940, **146**, 98.
27. B. P. PAL and B. B. MUNDKUR, Proc. Ind. Acad. Sci., 1939, **9**, 267–70.
28. B. B. MUNDKUR, Curr. Sci., 1943, **12**, 230–1.
29. G. N. PATHAK, Ind. J. Genet. Pl.-Breed., 1942, **2**, 37–42.
30. B. P. PAL and G. S. MURTY, ibid. 1942, **1**, 61–86.
31. B. P. PAL and N. ALAM, Proc. Ind. Acad. Sci., 1938, **7**, 109–24.
32. B. P. PAL *et al.*, Ind. J. Agric. Sci., 1941, **11**, 479–92.

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FURTHER INVESTIGATIONS ON THE ALLEGED TOXICITY OF COD-LIVER OIL FOR PIGS[1]

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We have previously reported [1] our inability to impair the health and growth-rate of fattening pigs by the prolonged feeding of high- and low-quality cod-liver oils, even in amounts far in excess of those used in ordinary pig rations. Our purpose then was to determine whether genuine cod-liver oils were capable of producing toxic effects in pigs, in particular the fatal liver dystrophy described by some continental workers. In our experiments, the pigs never showed any evidence of metabolic disturbance attributable to the feeding of cod-liver oil, nor were detectable lesions found in any of the internal organs (liver, kidneys, and heart) at post mortem.

We pointed out [1] that a possible source of the discrepancy between our results and those obtained by the continental workers lay in the different ages of the pigs used. Thus Nicolaus [2] states that only pigs weighing between 3 and 17 lb. became affected with toxic liver dystrophy. Wagener [3] succeeded in reproducing the disease under experimental conditions in 5 out of 8 pigs aged 6 to 8 weeks and weighing between 15 and 20 lb. Tiedge [4] observed the disease under farm conditions most commonly in pigs between 2 and 4 months old. The pigs used in our earlier experiments were considerably heavier than those of Nicolaus and Wagener, and the present experiments were, therefore, undertaken to determine whether there is an age susceptibility to the alleged toxic effects of cod-liver oil. At the same time we were afforded an opportunity of feeding other oils of marine origin which might possibly find their way into 'cod-liver oil' sold for animal food.

In 1935 workers at Cornell [5] reported that the inclusion of cod-liver oil in the diet markedly increased the severity and incidence of nutritional muscle dystrophy in rabbits, guinea-pigs, sheep, and goats, and later they concluded [6] that cod-liver oil and some other factor, which remained undetermined, were the causative agents. Similar degenerative changes in the skeletal muscles of guinea-pigs and rabbits had been earlier reported by Goettsch and Pappenheimer [7], who showed that a deficiency of one factor present in wheat-germ oil was involved in its causation. This finding was later confirmed by other groups of workers [8, 9]. Olcott [10], discussing the results obtained by the Cornell workers, quotes Cummings and Matill [11], who showed that the oxidative reactions initiated by the auto-oxidation of cod-liver oil were destructive to vitamin E. Similarly Mackenzie *et alii* [12], in reviewing possible explanations of the connexion between cod-liver oil and muscle dystrophy, suggest that the most likely explanation is the destruction of

[1] This work was carried out with the assistance of a grant from the Agricultural Research Council.

α-tocopherol by cod-liver oil following the ingestion of these two substances. Finally, Hammond [13], working with poultry, has obtained results indicating that there is a factor in cod-liver oil which hinders the utilization of vitamin E by the growing chick and leads to the production of encephalomalacia. In view of the foregoing reports referring to herbivorous animals and poultry, a subsidiary purpose in our present experiments was to obtain information whether the pig was susceptible to similar degenerative changes of skeletal muscle due to the possible destruction of α-tocopherol in the ration by cod-liver oil.

Experimental

The investigation was carried out in two separate experiments with a total of 16 pigs between the ages of 20 and 142 days. To detect any growth-retardation which might arise as a result of oil-feeding, the pigs were weighed at intervals during the experiments.

Dosage of oil.—In both the experiments the pigs were individually dosed with oil by the method already described [1]. All the pigs took the oils greedily with the exception of one pig (No. 14) receiving sperm oil.

In Expt. I a high-grade pure cod-liver oil, subsequently referred to as pure cod-liver oil, and controlled cod-liver-oil mixture were each fed to 2 pigs, whilst 2 pigs received no oil. Oil-feeding commenced when the pigs were 24 days old and weighed between 15 and 18·5 lb., with $\frac{1}{6}$ oz. (5 c.c.) of each of the oils given daily. This amount was gradually increased so that when the pigs were weaned at 54 days old they were each receiving 2 oz. of oil daily. Thereafter, and until the experiment ended, when the pigs were 104 days old, each received 4 oz. of oil daily, administered morning and evening just before feeding.

In Expt. II, dogfish-liver oil and sperm oil were fed in addition to two cod-liver oils of very low quality. Each of the oils was fed to 2 pigs, with 2 pigs acting as controls. Administration of $\frac{1}{2}$ oz. of each oil began when the pigs were 20 days old and weighed between 9·5 and 13·5 lb.; when they were 42 days old the dosage was raised to 1 oz. per day, and this amount was continued until they were weaned at 61 days old. From 61 to 142 days of age, when the experiment ended, each of the pigs received a daily dosage of 2 oz. of the respective oils.

Pigs.—The young pigs used in Expt. I were the progeny of a Large White boar × Wessex sow; those in Expt. II were pure Large White. The sows were purchased in an advanced stage of pregnancy and were farrowed in the experimental pens at the Royal Veterinary College, Sonning. All the parents were high-class pedigree stock, and the herd from which they were bought is tuberculin-tested and known to be free from any serious disease. The 6 pigs used in Expt. I were the total litter farrowed by the Wessex sow. The 10 pigs in Expt. II were members of a total litter of 16, 11 of which survived to weaning age.

Rations.—The rations used produced satisfactory live net gains and appeared to be generally suitable, although the ingredients were not always of the best quality.

The pigs in both experiments were still sucking when the oil-dosing

commenced. From the age of 3½ to 4 weeks onwards a meal mixture was made available in accordance with usual practice. After weaning, at 54 days in Expt. I, and 61 days in Expt. II, the mixture was fed in increasing quantities at the rate of approximately 1 lb. per 20 lb. live weight, adjusted to the nearest ½ lb. of meal. It was always fed as a wet mash in a common trough of adequate size, so that each pig should get its due share. A small amount of fresh green food was fed as regularly as circumstances would permit; water was available.

For the pigs in both experiments the meal mixture had to be varied from time to time according to what foods could be obtained. The general type consisted of barley meal, whole maize meal (or maize-germ meal) and weatings, equal parts; 6 to 10 per cent. of good-quality meat- and bone-meal added. In at least one consignment a Sussex ground oats of rather poor quality had to be used instead of maize meal.

Properties of the oils.—The more important chemical properties of the oils used are given in Table 1. Some explanatory details and references in respect of the technical production of cod-liver oils have already been given [1]. The pure cod-liver oil was an exceptionally high-grade

TABLE 1. *Experiments I and II. Particulars of the Oils used*

	Sample of oil	*Free fatty acid, %*	*Saponification value*	*Iodine value*	*Unsap. matter, %*	*Blue value*	*Vitamin A International Units per gm.*
Expt. I	Pure C.L.O.	0·225	185·6	154·7	1·07	20·0	1,760
	Controlled C.L.O. Mixture	0·367	186·7	153·0	1·30	10·4	760
Expt. II	Low-quality C.L.O. I	15·930	183·4	162·5	1·80	22·0	1,519
	Low-quality C.L.O. II	16·00	187·1	160·7	1·55	Nil	Negligible
	Dogfish-liver oil	0·197	168·2	122·7	11·32	6·8	524
	Sperm oil	Nil	129·6	81·1	42·10	Nil	Negligible

un-destearinated oil but which showed no stearin deposit at ordinary atmospheric temperatures. It was pale yellow with a bland but slightly fishy taste and smell. The controlled cod-liver oil mixture judged by its chemical properties was also a high-grade product. It was pale yellow, and always contained, even at high summer temperatures, a heavy white deposit (stearin) which, when shaken up, made the oil slightly turbid. It was bland to taste, but both odour and taste were somewhat less fishy than those of the pure cod-liver oil. Table 1 shows that the properties of this sample of controlled cod-liver-oil mixture correspond, apart from its blue value and vitamin-A content, fairly closely with those of the pure cod-liver oil. Oils designated as 'controlled cod-liver-oil mixture for animal feeding purposes' are produced under licence granted by the Ministry of Food, and consist of a mixture of cod-liver oil with a suitable diluent oil approved and supplied by the Ministry. Since the nature of the diluent oil varies from time to time, it is not possible to

specify the exact oil present in the controlled cod-liver-oil mixture used in the experiments. The British Standards Institution has, however, issued with the authority of the Ministry of Food a war-emergency specification [14] setting forth desiderata regarding the quality of controlled cod-liver-oil mixtures. The properties of the oil used in these experiments fall well within the limits stated in the B.S.I. specification.

The low-quality cod-liver oils I and II were produced from stale cod livers by the 'rotting process'. No. I was a thin oil of dark reddish port-wine colour, with a rancid smell and a somewhat bitter taste, reminiscent of sardines. No. II was a rather thick oil of a deep reddish-brown colour. It had very little smell and was bland to the taste. It will be noted from Table I that the chief difference between the quality of these oils and those described above lies in their high content of free fatty acids, a fact indicative of a badly produced and decomposing oil.

The dogfish-liver oil was experimentally prepared under good conditions from fresh livers. It was a pale yellow liquid, containing at ordinary temperatures a light dispersion of white floccules. At low winter temperatures this oil was a semi-solid mass, just capable of being poured. It had only a very slight fishy taste and smell, and was bland to taste. The chief feature distinguishing this oil from genuine cod-liver oil is its high percentage of unsaponifiable matter [15].

The sperm oil was a high-grade sample of neutral white sperm oil; it was clear and free from sediment or other insoluble matter, pale yellow, and of slightly bitter taste.

Results

In Expt. I the period of oil-feeding was 80 days and in Expt. II 122 days, the pigs being respectively 24 and 20 days old when the experiments began.

All the pigs survived till the end of the experiments. The symptoms of toxic liver dystrophy as described by continental workers were never observed in any of the animals.

A careful watch was kept for any abnormalities in gait which might be indicative of muscle lesions. Apart from a slight stiffness exhibited from time to time in one or other of the pigs, nothing abnormal was detected.

One of the control pigs in Expt. II developed clinical symptoms indicative of rickets soon after weaning; these progressively increased in severity until at the end of the experiment the pig was unable to stand. (Another pig, not in the experiments, fed on the same ration also developed apparent rickets.) One of the pigs in Expt. II, No. 14 on sperm oil, refused food between 100 and 110 days of age; its temperature was raised and signs of pneumonia were evident. Difficulty had always been experienced in getting this pig to take sperm oil and it had to be forcibly dosed. It is likely that during dosing some of the oil was aspirated into the trachea and lungs, thus causing the pneumonia. Oil-feeding was discontinued while the pig was ill.

Live-weight gains.—The pigs were weighed at intervals during the

experiments. Tables 2 and 3 give a summary of the live-weight increases during the period of oil-feeding.

TABLE 2. *Expt. I. Weight Increases during the Period of Oil-feeding*

Oil fed	Pig's No.	Weight (lb.)		Weight (lb.) increase between age of			
		At start of Expt.	At end of Expt.	24 and 54 days	54 and 80 days	80 and 104 days	24 and 104 days
Pure C.L.O.*	5	16·5	81	23·5 (0·78)†	15 (0·58)	26 (1·08)	64·5 (0·81)
	4	18·5	72	26·5 (0·88)	7 (0·27)	20 (0·83)	53·5 (0·67)
Controlled C.L.O. Mixture	2	16·5	69	30·5 (1·02)	5 (0·19)	17 (0·71)	52·5 (0·66)
	3	15	78	22·5 (0·75)	9 (0·35)	31 (1·29)	62·5 (0·78)
Controls	1	17	96	23·0 (0·76)	24 (0·92)	32 (1·33)	79·0 (0·99)
	6	16·5	92	25·5 (0·85)	18 (0·69)	32 (1·33)	75·5 (0·94)

* C.L.O. = Cod-liver oil. † Figures in brackets are the averaged *daily* weight increases.

TABLE 3. *Expt. II. Weight Increases during the Period of Oil-feeding*

Oil fed	Pig's No.	Weight (lb.)		Weight (lb.) increase between age of		
		At start of Expt.	At end of Expt.	20 and 61 days	61 and 142 days	20 and 142 days
Low-quality C.L.O.* I	8	11	119	22·5 (0·55)†	85·5 (1·06)	108·0 (0·89)
	11	13	131	25·0 (0·61)	93·0 (1·15)	118·0 (0·97)
Low-quality C.L.O. II	10	11	109	19·5 (0·48)	78·5 (0·97)	98·0 (0·80)
	12	13	104	20·5 (0·50)	70·5 (0·87)	91·0 (0·75)
Dogfish-liver oil	15	13·5	118	20·5 (0·50)	85·0 (1·05)	105·5 (0·86)
	9	11	131	25·0 (0·61)	95·0 (1·17)	120·0 (0·98)
Sperm oil	13	9·5	105	20·5 (0·50)	75·0 (0·93)	95·5 (0·78)
	14	13	91	22·0 (0·54)	56·0 (0·69)	78·6 (0·64)
Controls	7‡	11	58	17·5 (0·43)	29·5 (0·36)	47·0 (0·39)
	16	11	110	22·5 (0·55)	76·5 (0·94)	99·0 (0·80)

* C.L.O. = Cod-liver oil. † Figures in brackets are the averaged *daily* weight increases.
‡ Developed rickets.

In Expt. I all pigs made normal live-weight gains up to weaning at 54 days: at weaning the pigs were receiving 2 oz. of oil per head per day. In the period 54 to 80 days of age three (Nos. 4, 2, 3) of the four oil-fed pigs made very poor weight gains as compared with the controls. The

amount of oil given to the pigs during this period was 4 oz. per head per day. During the first week on this dose two of the pigs (Nos. 2 and 4) scoured badly, whilst in the other two (Nos. 3 and 5) the faeces were very soft and pultaceous. The faeces of all these four pigs smelt strongly of cod-liver oil, which was found in the excreta. From the age of 80 to 104 days the oil-dosage was continued at 4 oz. per head per day. During this period pigs 4, 2, and 3 showed no further signs of intestinal disturbance except that the faeces, now of normal consistency, smelt strongly of cod-liver oil. Three of the oil-fed pigs (Nos. 5, 4, 2) made somewhat poorer live-weight gains than the controls and the other oil-fed pig No. 3. When the pigs were 104 days of age, oil-feeding was stopped and two of the oil-fed pigs (Nos. 2 and 4) were killed for post-mortem. The other pigs in the experiment were fed to bacon weight, which they attained in the normal time, although the two oil-fed pigs were still somewhat lighter than the controls.

In Expt. II all the oil-fed pigs and one of the controls made normal live-weight gains during the period 20 to 61 days of age. At weaning these pigs were much lighter than the pigs in Expt. I, as might be expected from the considerably greater number in the litter. During the period 61 to 142 days of age all the pigs with the exception of one control pig (No. 7) and one of the pigs (No. 14) on sperm oil made comparable gains. The reasons for the poorer gains in these two pigs have already been indicated.

Post-mortem examination.—Pigs Nos. 2 and 4 of Expt. I and Nos. 14 and 7 of Expt. II were killed at the end of the oil-feeding period for post-mortem examination.

In pigs Nos. 4 and 2 no gross abnormalities were detected. In pig No. 7 the clinical diagnosis of rickets was confirmed. In pig No. 14 there were areas of slight consolidation in both lungs, consistent with pneumonia from which this pig suffered during the oil-feeding period.

A careful search was made of the intestines of all the pigs for worm infestation. No worms were found.

As in our earlier report, the heart, liver, and kidneys were weighed immediately after slaughter. The weights (Table 4) of these were considered to fall within the normal ranges.[1]

TABLE 4. *Expts. I and II. Weights of Various Organs of Pigs killed for Post-mortem Examination*

	Pig's No.	*Pig's age (days)*	*Oil fed*	*Weight of heart (gm.)*	*Weight of liver (gm.)*	*Weight of kidneys (gm.)*	*Live weight when killed (lb.)*
Expt. I	4	104	Pure C.L.O.	142·50	716·09	138·75	72
	2	104	Controlled C.L.O. Mixture	123·75	746·09	131·25	69
Expt. II	14	142	Sperm oil	187·50	1012·18	277·50	91
	7	142	Control	150·00	656·09	127·50	58

[1] We are indebted to Dr. Charles Crowther for pointing out that there appears to be a significant increase in the weights of the kidneys of the oil-fed pigs, and an even more remarkable increase in the weights of the livers. An increase in kidney weights

Pieces of liver and right gastrocnemius muscle, diaphragm and heart muscle, from each of the four pigs, were fixed immediately for later histological examination. Microscopic examination of stained sections from these tissues showed that they were normal.

The post-mortem findings together with the absence of clinical symptoms during life confirm the view that no toxic liver dystrophy or degeneration in the heart or skeletal muscle was produced in our experiments.

Discussion

As in the earlier work with older pigs [1], we failed to reproduce the fatal toxic liver dystrophy in young pigs described by several continental workers. In this and in the earlier series of experiments we have tested nine different samples of cod-liver oil of varying quality, and administered these oils in doses far in excess of those used by the continental workers. We have also shown that toxic liver dystrophy is not caused by the feeding of dogfish-liver oil or sperm oil. It seems unlikely, therefore, that this disease can in fact be attributed to any *direct* toxic effect of cod-liver oil or of other marine oils, such as dogfish-liver and sperm. This, of course, does not exclude the possibility that cod-liver oil may not increase the severity of toxic liver symptoms which may be due to some unknown cause.

In 1939 we directed attention to several possibilities which might account for the discrepancy between our results and those of the continental workers. Since we have entirely failed to produce toxic liver dystrophy in any of our experimental pigs, it would be purposeless to speculate further on the aetiology of this condition. It is considered unlikely that, under practical conditions of pig husbandry in Great Britain, cod-liver oil in the amounts added to the foodstuffs normally used in pig-feeding could ever give rise to toxic liver dystrophy.

In Expt. I the finding that excessive doses of cod-liver oil markedly retard growth-rate is in agreement with the reports of many other workers. To cite only one of the numerous articles on this subject, Bell, Gregory, and Drummond [16] showed that rats do not show a normal growth-rate on diets containing 15 per cent. of cod-liver oil. Various hypotheses have been advanced to explain this connexion, but no toxic fraction in the oil has yet been conclusively incriminated. In our work it was found that pigs between the ages of 54 and 80 days and weighing up to 52 lb. were unable to tolerate a dose of 4 oz. of cod-liver oil per head per day, which caused diarrhoea at first and at a later stage produced soft, oily faeces. It seems possible that the growth-retardation in this case at any rate may have been caused by the mechanical laxative effect of the unabsorbed fractions of the large doses of oil administered, rather than by any purgative or toxic principles present in the oil. The rapid passage of food through the intestine and the incomplete absorption resulting therefrom seem sufficient to cause lower weight-gains than those in the pigs not receiving oil.

of pigs fed with cod-liver oil was recorded in experiments at the Harper Adams Agricultural College in 1935–6 [17].

In view of the muscle dystrophy reported by workers in the U.S.A. to be caused in herbivorous animals by the inactivation of vitamin E by cod-liver oil, it is noteworthy that no muscle lesions were found in the pigs used in our work, even though the amounts of oil fed to the pigs were proportionately much greater than those used in American experiments. From this it would appear that the pig may be less susceptible to the degenerative changes in skeletal muscle due to deficiency of vitamin E than are some herbivorous species. To settle this point, however, it would be necessary to subject pigs to a longer period of oil-feeding than that used in our experiments.

Summary

1. The feeding of four different samples of cod-liver oil, one sample of dogfish-liver oil, and one of sperm oil to pigs, between the ages of 20 and 142 days, in amounts up to 4 oz. per head per day failed to produce the toxic liver dystrophy described by continental workers.

2. No evidence was obtained that pigs are susceptible to the degenerative changes in skeletal muscles (muscle dystrophy) resulting from the destruction of vitamin E in the diet by cod-liver oil, as has been reported for herbivorous animals.

3. Post-mortem examination of the pigs fed with the oils confirmed the clinical observations. Histological examination of sections made from the liver, heart muscle, diaphragm, and skeletal muscle revealed no abnormalities.

4. The feeding of 4 oz. of cod-liver oil per head per day caused a marked growth-retardation in three out of four pigs between the ages of 54 and 80 days.

5. It is suggested that growth-retardation in these pigs may have been due to the mechanical laxative effect of an excessive intake of cod-liver oil, rather than to a specific growth-retarding factor present in the oil.

6. The experiments here reported confirm the view that genuine cod-liver oil, or marine oils such as dogfish-liver or sperm, are not primary aetiological factors in the causation of toxic liver dystrophy, even when administered to pigs in excessive amounts.

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(The work reported in this paper was completed in 1942. The considerable delay in publication has resulted from the loss of the completed original MS., which necessitated the rewriting of the paper from the experimental records.)

REFERENCES

1. N. J. Scorgie and W. C. Miller, Empire J. Expt. Agric., 1939, **8**, 357.
2. W. Nicolaus, Tier. Rsch., 1937, **43**, 387, 401, 678.
3. K. Wagener, ibid., 1936, **42**, 789.
4. F. L. Tiedge, Dtsche. Tier. Wschr., 1937, **45**, 132.
5. L. L. Madsen, C. M. McCay, and L. A. Maynard, Cornell Univ. Agric. Expt. Stat., 1935, Memoir No. 178.
6. G. Davis, L. A. Maynard, and C. M. McCay, ibid., 1938, Memoir No. 217.
7. M. Goettsch and A. M. Pappenheimer, J. Expt. Med., 1931, **54**, 145.
8. S. Morgulis and H. C. Spencer, J. Nutrit., 1936, **11**, 573.
9. C. G. Mackenzie and E. V. McCollum, Sci., 1939, **89**, 370.
10. H. S. Olcott, J. Nutrit., 1938, **15**, 221.
11. M. J. Cummings and H. A. Matill, ibid., 1931, **3**, 421.
12. C. G. Mackenzie, J. B. Mackenzie, and E. V. McCollum, ibid., 1941, **21**, 225.
13. J. C. Hammond, Poultry Sci., 1941, **20**, 369.
14. War Emergency British Standard Specification for Controlled Cod-liver Oil Mixture for Animal Feeding Purposes, British Standards Institution, 1940, No. 910.
15. C. C. Harris, Chem. and Ind., 1938, **57**, 508.
16. M. E. Bell, E. Gregory, and J. C. Drummond, Sond. Z. Vitaminforsch., 1933, **2**, 161.
17. C. Crowther and T. S. Wright, Pig Breeders' Annual, 1936–7, **16**, 129; also E. H. Callow, Rept. Food Invest. Board, 1936, pp. 69–73.

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AGRICULTURE IN THE GOLD COAST[1]

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THE Gold Coast consists of nearly 59 million acres with a population of about 3·6 millions. The three main climatic and vegetative regions are the Northern Savanna of 36 mill. acres, the closed Forest Area of 17 mill. acres in which all the cocoa is grown, and the Coastal Savanna of not more than 6 mill. acres. Practically the whole country is suitable for agriculture, but a considerable area in forest is necessary to protect the cultivation of tropical plantation crops. The population is increasing by 15 per cent. in a decade, and the land could support a population at least four times greater than the present.

1. *Food Farming*

Food Supplies. The first function of agriculture is the production of food for local consumption. Despite the import of considerable quantities of foodstuffs, food-farming occupies more people and produces in bulk far more than any other industry. Famine is almost unknown, but local scarcity of foodstuffs occurs periodically in the heavily populated North Mamprussi area.

Nutrition. Carbohydrate foods such as plantains, yams, cassava, or cocoyams form the bulk of the diet, to which is added protein in the forms of snails, fish, meat, poultry, and vegetable oil, especially palm oil rich in carotene. There is evidence of deficiencies of protein, some vitamin, and some elements, especially in the outlying and heavily populated districts. The production and consumption of protective foods like vegetables and fruits is relatively small and of milk almost negligible. By European standards the consumption of meat is small.

Crop diseases and pests. On the whole, field crops are fairly free from diseases and pests.

Crop-breeding. Breeding and selection of field crops was begun by the Department of Agriculture a few years ago; the desired characters are disease-resistance, early maturity, drought-tolerance, palatability, capacity to withstand long storage, ease of preparation, resistance to wind-damage and to pests, such as insects and birds. Considerable progress has been made in the breeding of guinea-corn and cassava. There is also scope for improvement of fruit-trees and all kinds of vegetables.

Animal diseases and pests. The most important diseases of animals are rinderpest and trypanosomiasis. Rinderpest has been brought under control by the Department of Animal Health. Trypanosomiasis continues to prevent the keeping of cattle in the closed forest area, but

[1] This article is an abbreviated version of a review prepared by the author in 1940, to which he has added a summary of a memorandum reviewing progress to the end of 1942.—EDIT.

some local breeds tolerate the disease fairly well in savannah country.

Stock-breeding. Some breeding has been done for a few years by the Department of Animal Health, but the scope for stock improvement is wide.

Self-sufficiency. The development of the large export trade in cocoa has led to a large import trade, and considerable quantities of foodstuffs have been imported annually for many years. In 1939 the imports of animal produce, crop produce, fish, and tobacco amounted to £1,374,733, or one-fifth of the value of the imports of all merchandise. The most important items are animals, meat, wheat and flour, sugar, and rice, but considerable quantities of milk, butter, vegetables, edible oils, and pulses were also imported. Some of the imports, e.g. wheaten flour, cannot be replaced by local production.

The control of animal disease by the Veterinary Department, especially that of rinderpest in cattle, has opened the way for a large increase in the production of locally grown meat. Feeding trials have shown that the quality of beef, mutton, and pork can be remarkably high. Abundant grazing is available throughout the savanna country, and even in the closed forest there is plenty of green-feed for more small live stock, especially sheep. An increase in the production of beef, mutton, pork, poultry of all kinds, but especially beef, is also desirable.

The production of milk to take the place of imports is a long-range problem. At present local cows seldom produce enough milk to feed the calves properly, let alone a surplus for human consumption. Recent trials at Pong Tamale have shown that the most promising types of milk-producer are those least able to survive attacks of trypanosomiasis and so cannot be kept in health where the incidence of tsetse flies is high.

Sugar-cane grows well in the Gold Coast. The local demand could be filled with the establishment of a large mill with a large plantation under its control, but not by a number of suppliers of small quantities of cane. The high price of sugar in war-time makes the planting of sugar-cane desirable, and small-scale extraction of sugar should be investigated.

The annual import of rice is large. Small quantities of swamp rice are grown at Esiama, and hill rice in outlying food-farming areas. The high price of imported rice in war-time makes an increase in the production of rice desirable.

Imported vegetables are mainly potatoes and onions, and also canned and fresh vegetables from temperate climates. There is scope for the local production of large onions; spring onions and small onions are being produced locally in increasing quantities.

The import of edible oils consists principally of palm oil from Nigeria. This is largely a matter of distribution, because almost as much palm oil is exported from the Gold Coast. In addition, coconut oil, groundnut oil, and shea butter are produced locally. Cocoa is also available, in connexion with the Cocoa Control Scheme, for the extraction of cocoa-butter and for the preparation of cocoa and chocolate for local consumption.

Imports of beans and peas are mainly from Nigeria and French Togo-

land. An increase in the local supply would be advantageous both as regards self-sufficiency and in view of the effect they have in maintaining soil fertility.

Several systems of farming have been adopted by African farmers in the savanna areas. In North Mamprussi the farmers live in scattered compounds and cultivate intensively the land round their dwellings. In thinly populated areas, such as Dagomba, they live in compact villages and practise shifting cultivation under which a piece of land is farmed for 2–4 years and then left fallow for 6 years or so. In parts of Keta district the land is fallowed in rotation.

Mixed farming. In all the systems, although cattle are available and often owned by the farmer, little use is made of them on the farm. Experiments at Zuarungu and Tamale have shown that systems of 'mixed farming' are better than the native methods in almost every way, raising fertility and giving higher yields. Its extension to other areas is proceeding gradually. In savanna areas mixed farming is the best method by which famine can be overcome, nutrition improved, erosion prevented, fertility improved, surplus food produced for sale, and a firm foundation laid for a sound rural economy.

Farmyard manure. Most important in mixed farming is the proper preparation and use of farmyard manure. Demonstrations have been given to farmers, several of whom have adopted methods of farmyard manuring suited to their conditions.

Ploughing. The second stage is the use of working bullocks to plough and cultivate, and several farmers now use them, but only 'mixed farmers' who have adopted farmyard manuring are assisted to plough. The introduction of ploughing involves the supply and training of bullocks, the supply of suitable ploughs and cultivators, the training of farmers in their use, and instruction in such matters as the necessity for ploughing along contours and not up and down hill. Where necessary, advances for the purchase of implements are given from Native Administration funds and are repaid over a number of years.

Other improvements in food farming. Among other improvements are the management of pastures and temporary leys, the use of fenced paddocks, the use of supplementary feed and fodder in the dry season, and the control of soil wash in ploughed fields. Root crops for food and leys of legumes and grass have great possibilities. The object is to discover how an improved practice can be incorporated into the local system of farming in a way that will appeal to the farmer.

Grass fires. In the Northern Territories grass-burning is regulated or prohibited by rules enforced by the Native Authorities. The beneficial results are to be seen in the improved grass sward.

Extension of farms. In some areas development is prevented by lack of roads or water-supplies, or the prevalence of tsetse fly. The provision of capital improvements in these respects is a form of development which is greatly needed not only in undeveloped areas but also in some settled areas.

Forest food-farming systems. In the closed forest area the prevalence of tsetse fly has rendered the keeping of cattle unprofitable. The

farmers live in villages or towns, and the production of cocoa is their chief pursuit. The local food supply is supplemented by importations from food-producing areas and from overseas. Forest crops, such as plantains and cocoyams, and arable crops like maize, peas, and cassava are grown on young cocoa farms or under shifting cultivation. In either case the land does not remain cultivated long but reverts to trees or secondary bush. It is probable that in the closed forest area some form of shifting agriculture will remain the mainstay of native arable farming. Sir Frank Stockdale has written that it should be the aim of all agriculturists in the wet tropics to maintain or to reproduce as far as is practicable the conditions which prevail when the land is under forest cover, and that where the conditions are not suitable for the marriage of animal husbandry with crop production, the latter must proceed along lines which conform with the dictates of nature. This is endorsed by experience in the Gold Coast. Shifting cultivation is the best system of crop farming for the wet forest area and is to be preferred to continuous arable cropping. It becomes a menace when pressure of population necessitates greater food-crop production and an inadequate period for regeneration under forest cover. Research on the subject must consider the manurial value of sheep and other small live stock, composting, and green manuring, not only to keep the land longer in cultivation but to reduce the fallowing period. The extent to which cleared fields and continuous cultivation are permissible in the closed forest area will depend on the effect of clearings on the humidity of the air and, possibly, on the evolution of cocoa strains that thrive under less humid conditions than pure *Theobroma leiocarpa*. Forest food-farming systems have been studied at several unit farms, but real progress is unlikely in the absence of an experimental station in the forest area and special staff to devote the whole of their attention to it.

Summary. The main conclusions to be drawn are the primary need to protect farming by the continuance of the control of animal disease, the importance of improvement by the introduction of mixed farming, the need for a greater production of meat, rice, beans, poultry products, sugar-cane, fruit, and vegetables, and the need for agricultural research.

2. *Cocoa Production*

Cocoa is the staple export crop and the largest 'money' crop for Gold Coast farmers. Upon the export of cocoa chiefly depends the economic prosperity and financial stability of the Gold Coast. Expanding from embryonic size at the beginning of this century, it has now reached the large production of nearly 300,000 tons of cocoa a year.

In the Gold Coast under forest conditions on virgin forest soil the crop has given higher yields than in other parts of the world. The method of planting has fitted in well with native methods of food-growing under shifting cultivation. The crop has required a minimum of attention; it has not demanded that the grower should live on his plantation, and a standard of quality acceptable to the trade has been achieved. The period of expansion of production coincided with ex-

panding consumption, and prices have been remunerative and even high in comparison with those of other exportable produce.

The maintenance of the cocoa industry presents some problems. The 1938 Nowell Cocoa Commission expressed the view that much would depend on whether measures were taken to regulate the use of land, and on the progress made in agricultural practices; and recommended that a careful watch should be maintained on the expansion of cocoa-farming and the location of farms, with a view to appropriate action when and where its necessity was indicated, and that district land surveys in some suitable form should be instituted. Various reports have stated that the cocoa on many farms is dying, through neglect or through pests and diseases beyond the farmers' control. The trees have been left to nature and little attempt has been made to improve them by pruning or cutting out epiphytes. Many farms have given lower yields after a few years' heavy cropping. Newly planted farms have taken longer to come into bearing than they did 20 years ago, young cocoa has often been found difficult to establish owing to pests, and the re-planting of old farms has usually been unsuccessful.

Forest reserves. Cocoa requires a good rainfall and a humid climate. The maintenance of such conditions is essential and this requires a sufficiency of closed forest. This has long been recognized by the Forestry Department, whose chief aim is to maintain and improve these tropical climatic conditions, especially by means of forest reserves.

Swollen-shoot disease. At the moment the greatest threat to cocoa production is swollen-shoot disease, which came to light some few years ago and has not been recorded elsewhere. It is now a serious menace to the industry. Recent research proved that swollen shoot was sap-transmissible and provided evidence that a slow-moving Psyllid insect could transmit it from an infected to a healthy plant. The insect vector is widely spread in the cocoa areas and feeds also on shoots of species of Cola. Every cocoa tree observed to be infected with the disease has died within a year. Seedlings planted in infected areas have become affected, and it is now clear that the disease has been responsible for devastation in such areas as Nankese. Surveys of the limits of the incidence of infection have been made with a view to determining whether control by natural barriers is practicable. It appears that the disease occurs only in a limited area in the Eastern Province, and that it should be possible to delay the rate at which it spreads even though it may be impracticable to confine it.

In the long run the breeding and selection of immune or tolerant strains of cocoa is likely to provide the only satisfactory remedy. In the search for resistance there is no lack of material, as there are several local strains of cocoa, and many other varieties and strains can be introduced from Central America.

Present knowledge shows that there is a good prospect of delaying the spread of the disease with the aid of 'cocoa-free' belts of country, by regular patrolling, and by the eradication of outbreaks that occur farthest from the heavily infested area. The method of treating an outbreak is to cut down infected and adjacent trees after spraying with

a suitable insecticide, and then to spray and observe the area until the outbreak has been destroyed. To attempt control in heavily infested areas is impracticable, but the destruction of outbreaks in ever-narrowing circles from the perimeter might well confine the disease and at least delay the spread in the years during which the search for resistant varieties is pursued. There appears to be a good chance that by using these methods the spread of the disease to Ashanti, to the Central Province, and to some areas in the Eastern Province can be prevented. Uncontrolled, the disease would wipe out the cocoa plantings in ever-widening circles.

Sahlbergella. The effect of the ravages of Sahlbergella is increasing. Repeated attacks of Sahlbergella blast weaken the adult tree, which becomes a prey to other enemies and prematurely dies. Young cocoa is sometimes attacked to such an extent that the grower finds he cannot establish a new farm. Much is known of the life-histories and habits of the insects concerned, but methods of control that are economical and practicable have yet to be devised.

Other diseases and pests. The catalogue of other diseases and pests of the cocoa tree is long. They are mostly minor pests, but some are potential major pests. To treat them as 'physiological', or regard them as 'die-back', provides no method of treatment or cure. Methods of control require to be worked out and, when necessary, applied. It seems that cocoa in its rapid development outstripped its enemies, which, now that they are catching up, have in turn outrun their own.

Cocoa-breeding. Cocoa-breeding has only recently been started in this country. Strains of cocoa are needed that are resistant to swollen shoot and to other diseases and pests, and also strains more suited to existing and expected conditions of soil and climate, and with improved yield, bean quality, and bean size.

Shade and shelter. A campaign for the restoration of shade and shelter in the cocoa areas suffering from drought and exposure was initiated by Government in the light of the 1937 Report of Mr. H. A. Dade. Considerable progress has been made, but the discovery that swollen shoot is a transmissible disease has necessitated some modifications of the campaign. Reafforestation is sound practice but is not a cure for swollen-shoot disease.

Other improvements. The use of improved practices is demonstrated to farmers by the Department of Agriculture. More remains to be learnt of the effect of overhead shade, lateral protection, manuring, mulching, soil conditions, air conditions, moisture, humidity, and other environmental factors, on the health, yield, and longevity of the tree and on the fertility of the soil.

Systems of cocoa-farming. When a cocoa farm ceases to give an adequate yield the local practice is to neglect it, sometimes after growing a yam crop with the cocoa trees as supports and sometimes after selling the trunks and branches as fuel; the farm then reverts slowly to secondary bush. This fallowing period is usually considered desirable by the farmer, who presumably intends later to clear and plant with food crops and interplant another stand of cocoa in accordance with the practice

used for the original planting. Research is necessary to determine suitable agricultural and silvicultural practices for the development of 'rotations' or long-term 'shifting-cultivation' systems under which cocoa is the principal crop; the Forestry and Agricultural Departments are collaborating in this important line of work.

Cocoa establishment. The establishment of cocoa is more difficult now than formerly, owing to the ravages of Sahlbergella, and planting in old cocoa farms has usually been unsuccessful. The adequate provision of shade and the need to regard cocoa to some extent as a rotation crop are factors that affect the methods of establishment. The primary object of plant-breeding here is to issue seed of improved types, but vegetative propagation is not being neglected, as its importance will increase if plant-breeding methods prove too protracted with such a slow-maturing crop. The determination of sound practices for the establishment and re-establishment of cocoa has therefore become increasingly necessary.

Maintaining output. A major problem is whether the cocoa industry should aim at expansion, the *status quo*, or limitation of output. The indications are that, if present tendencies continue, the existing output of cocoa from the Gold Coast will hardly be maintained. There is no improved agricultural practice in view that will increase production abnormally during the next five years. The indications are that after the war central Europe will provide an expanding market for tropical produce like cocoa. Provided that continuous stretches of cocoa farms are avoided and sufficient forest and trees preserved in each area, a strong case can be made for a moderate extension of cocoa farms, the effect of which might be expected to maintain and slightly to increase our cocoa output. No special measures are needed to encourage such plantings, because new cocoa farms are, in fact, being established. The need to regulate new plantings is dealt with under the heading of 'Land-planning'.

General. The Cocoa Research Station, Tafo, conducts major lines of work on behalf of West Africa, and the Cocoa Research Scheme, Trinidad, deals with more fundamental issues on behalf of several Governments, including the Gold Coast; close collaboration is maintained. Urgent needs for the efficient conduct of cocoa research in the Gold Coast include the importation of all available species of Cacao from Trinidad and the American continent in order to provide more varied material for plant-breeding, and the conduct of searches for parasites of Sahlbergella in Central Africa and possibly in Central America.

3. *Other Crops and Produce*

In the early years of the twentieth century the most important agricultural exports were rubber, ranging from £100,000 to £350,000 a year, palm oil, from £100,000 to £200,000 a year, and palm kernels, from £75,000 to £175,000 a year. They were superseded by cocoa in 1906, when 8,975 tons, valued at £336,000, were exported. The following are the chief agricultural exports in 1939, when 280,709 tons of

cocoa valued at £5,101,219 were exported: 4,633 tons of kola nuts (£101,130), 2,654 tons of citrus-lime products (£51,774), 678 tons of rubber (£33,138), 4,467 tons of oil-palm products (£31,905), 1,040 tons of coconut products (£6,931), 98 tons of hides and skins (£4,524), 946 tons of bananas (£4,309), 43 tons of coffee (£1,434). Except for hides and skins, none of this produce was produced in the Northern Territories, which has considerable food markets to supply before considering the possibilities of exporting overseas.

Production

Kola. This is principally a West African trade. As an indigenous forest crop the kola tree is naturally suitable for cultivation in the forest areas in the Gold Coast, although some kola pests have transferred their attention to cocoa with possible serious consequences to the cocoa industry. In general the industry has been allowed to take its course; no measures have been found desirable to protect and improve it.

Limes. The lime industry in the vicinity of Asebu in the Central Province owes its inception to successful experimental plots at Asuansi Experiment Station. Messrs. Rose & Company established a factory some 10 years ago for the processing for export of lime products; owing to the limited market, farmers were advised not to plant too large an area and so far the company has been able to purchase all fruit offered. The area planted, in scattered plots, to limes is estimated at about 4,500 acres. Many of the old trees are attacked by gummosis and loranthus and many have been planted too closely. New plantings continue to be made. The value of exports has risen from £13,768 in 1933 to the record, in 1939, of £51,774, of which £38,319 was that of fruit juice. The industry has not been subsidized by the Government and no control has been exercised over the price paid to farmers for fruits, although farmers have frequently expressed dissatisfaction with the prices paid.

Rubber. The export of rubber has shown a steady increase since 1933, and the quantity of rubber exported in 1939 was about one-third of that of the record year of 1904, when the price was four times higher; 400 to 450 tons annually are produced from Hevea plantations and the fluctuating remainder from indigenous Funtumia trees which occur widely in cocoa areas. Hevea rubber can be grown profitably on plantation lines; it grows well in the wetter parts of the forest area. Except for the provision of instruction in preparing Funtumia sheet rubber, no measures have been taken for assisting this industry.

Oil palm. Since the beginning of the century the export of palm oil has declined from over 10,000 tons a year to less than 1,000 tons, and the export of palm kernels has been halved. More nuts are cracked and kernels sold when the price is rising or good. Much palm oil is prepared by native methods and consumed locally. The oil palm occurs as a predominant species in a narrow belt bordering the coastal savanna, but it also grows throughout the forest area. In the Western Province there is a palm-oil mill at Butre which obtains supplies of

fruit from a concession area; the company has recently established a 1,000-acre plantation from selected seed. The Bukunor palm-oil mill in the Krobo area was established under a scheme whereby the Government guaranteed an adequate supply of fruit or a subsidy instead, but it was obliged to close in 1939 owing to inadequate supplies of fruit. Hand-extraction palm-oil presses and hand-driven nutcrackers have made no appeal to farmers. Owing to the destruction of oil-palm trees for the production of palm wine, native states have introduced by-laws to replace felled trees or to prevent felling. In accordance with the recommendations of the Third Conference of West African Agricultural Officers, the major lines of research on oil palm are being conducted in Nigeria.

Coconut. In recent years copra exports have declined but coconut planting has increased. Under a scheme sponsored by the Department of Agriculture, many seedlings, covering 8,000 acres, have recently been planted near the coast between Axim and Half Assini. A suitable copra drier has been devised and several have been erected. When domestic consumption of the nuts and oil has been satisfied, there is expected to be a considerable export of copra. Plantings of coconut palms are also being made along the coast to the east.

Hides and skins. The export to the value of £4,524 in 1939 was lower than usual. Improvements in preparation are in the hands of the Animal Health Department.

Bananas. A banana export trade amounting to nearly 100,000 bunches a year has been developed in the Western and Central Provinces. Four ships owned by Elder Dempster & Co., Ltd., were provided with storage space for about 5,000 bunches each. The producers consist of two European-owned concessions and about 250 native farmers. One of the European companies, the West African Mahogany Co., Ltd., is at present relieving the Government of the necessity for financing the industry by purchasing bunches produced by farmers at the standard rates of 1*s.*, 9*d.*, and 6*d.* for 9-, 8-, and 7-hand bunches respectively. The Department of Agriculture maintains a service for supervising the supply and preparation of bananas for each shipment. Standards of quality are maintained. A constant look-out is maintained for Panama disease. Research work is being undertaken into cultivation methods necessary for the production of continuous supplies of large bunches. This export industry cannot yet be regarded as commercially established; it is still experimental, especially in regard to its suitability as a crop for local farmers.

Coffee. A decade or so ago the planting of coffee was stimulated by a Government payment of £5 for every acre properly established. There are now several small plantations in Ashanti, in the Eastern Province, and in South Togoland, mostly of the Robusta variety. A few power-driven hullers for dried cherries are in use. The industry is capable of supplying adequate supplies of coffee of Robusta quality for the local market, but the prospects for the development of an overseas trade are limited.

Cotton. There is a small cottage industry in cotton in the mandated

area of Togoland. Efforts to increase production for export from the Northern Territories have been discontinued. Cotton is not a profitable crop for export owing to low prices and low and erratic yields.

Grapefruit. About 150 acres of Marsh grapefruit have been established by citrus-lime growers near Asuansi, and Rose & Co., Ltd., are purchasing the fruits, none of which are commercially seedless, for juice-extraction. There are no technical difficulties in canning local grapefruit, which is excellent for the purpose. Research work is being continued at Asuansi with a view to producing commercially seedless varieties and for the protection of fruits from damage by citrus-fruit piercing moths. The need to exclude punctured and seeded grapefruit from shipments, and over-production in other parts of the world, will militate against the establishment of an export industry.

Oranges. Orange trees grow well in the Gold Coast, especially in areas of good rainfall bordering the closed forest zone. Local green oranges have from time to time been placed on the home market, but though sweet and juicy their green colour, indifferent peeling, and liability to mould have gone against them. The mould has almost invariably been caused by the punctures of fruit moths. A special investigation into these fruit moths, which also attack tangerines, grapefruit, and lemons, but not limes, is now being undertaken by a special entomologist with the aid of the Colonial Development Fund on behalf of the Gold Coast and Sierra Leone. In certain seasons of the year the moths damage 90 per cent. of the fruits. Research work to select the best types to grow for sale locally and possibly for eventual export is centred at Asuansi.

Groundnuts. About 7 years ago an attempt was made to foster an export groundnut industry from Ashanti. The price for export was so much lower than the price in the Kumasi market that the increased production was not in fact exported but was absorbed in the local markets. There are possibilities in the local expression of oil, especially in the extreme north.

Cassava starch. Cassava is a staple food crop in the southern part of the Gold Coast. It is cultivated to a greater extent than other crops in the coastal savanna belt, and a ready market for the produce is found in the coast towns and inland cocoa centres. Several hundred tons of peeled dried root (*kokonte*) have recently been exported, in view of the higher war price, and the possibility of creating an export trade in cassava starch or flour is being investigated.

Castor. In an attempt to develop an export industry in castor from the Akwapim plains very poor yields were obtained and the project was abandoned.

Shea. The vast number of wild shea trees in the Northern Territories has invited exaggerated estimates of the quantity available for export. Unfortunately the nuts or the extracted butter cost more to prepare and send to overseas markets than they are worth when they get there, and consequently no export has materialized. Shea butter is a useful fat for domestic use. The progeny of trees selected for yield performance is under observation.

Sisal. A full-scale trial on plantation lines failed. It is a useful plant to grow for local rope-making.

Tobacco. There is a small tobacco industry in the Eastern Province and the Magnum Prior strain of tobacco is becoming increasingly popular with farmers for local consumption.

Other crops, methods, diseases, and pests. The search for new crops continues. Derris has not been thoroughly tried. High nicotine-content tobacco might supply the nicotine insecticide for the spraying of cocoa against swollen-shoot disease and Sahlbergella. The local oyster nut, Belfairia, is worth trial. White kola nuts, Nganda coffee, and Brazil nuts should be thoroughly tested. In addition, the watch for new methods and processes continues, especially with the aid of Imperial Bureaux and Institutes. Diseases and pests are prevented from entering the country by plant-inspection services, and a constant look-out is kept for diseases and pests.

Produce Marketing

Much attention has been devoted to cocoa-marketing problems. The quality or purity of cocoa has been maintained with the aid of regulated produce-inspection established up-country and at seaports. Joint marketing has been fostered through the medium of cocoa co-operative societies. As a war measure the marketing of the cocoa crop has been entrusted to a West African Control Board, and the price to farmers has been guaranteed by H.M. Government. Several export industries other than cocoa have been assisted by marketing services from time to time.

Cocoa control. Shortly after the outbreak of war H.M. Government undertook to purchase the Gold Coast cocoa crop for the year 1939–40 and, later, the 1940–1 crop also.

Quality of cocoa. The maintenance of the purity and quality of cocoa under a comprehensive scheme of grading and inspection was adopted by the Government as a definite policy in 1937. Under the relevant Ordinance cocoa has to be thoroughly dry before it can be transported to larger centres of purchase, and thoroughly dry and free from foreign matter before it can be exported overseas. All cocoa has to be graded in accordance with prescribed standards for Grades I, II, III, and sub-grade. This legislation provided for a system of licensed graders, under which exporters are authorized to inspect, grade, and seal their own shipments. All the larger exporting firms except one have made use of this system, and four-fifths of the cocoa has been graded in this way. The cocoa of all other exporters is inspected and graded by the Department of Agriculture, which also maintains an inspection service at ports to check the purity of cocoa dealt with by licensed graders.

Cocoa-marketing co-operative societies. After several years of tentative efforts by the Department of Agriculture, the encouragement of co-operative societies was adopted as the official policy of the Government in 1931. Progress made during the first decade has compared favourably with that in other countries. At the end of 1939 there were 400 societies and over 10,000 members. Paid-up share capital was more than

£30,000. The societies have marketed nearly 10,000 tons of cocoa in a year and issued loans to members of nearly £12,000. The Co-operative Branch of the Department of Agriculture exercises strict supervision over the operations of the societies, and assists them to become self-supporting, but its main function is to encourage the slow voluntary development of the co-operative societies idea on an expanded basis with friendly guidance.

Cocoa destruction. Owing to the war a proportion of the crop has to be disposed of in order to make room for the next crop; deterioration during storage renders long storage uneconomical. The cheapest method of disposal is to burn in fairly large heaps, but sufficient is being held for distribution to those who wish to extract cocoa-butter or cocoa-powder for household consumption, cooking fat, lighting oil, soap, candles, cocoa drink, and chocolate. Cottage methods of preparation are being demonstrated and form the subject of propaganda. Measures to prevent the breeding of cocoa moth in such cocoa and to prevent the cocoa coming on the market again are being undertaken simultaneously.

Produce other than cocoa, and local foodstuffs. In general, marketing of crop-produce has been left to private enterprise, but the Government has provided marketing services when needed, as, for example, for bananas, and also inspection services in several cases to maintain quality. Some co-operative societies have also been planning to control the marketing policy of their own produce. The need for such measures in order to secure the efficient marketing of export produce other than cocoa is as great as for cocoa itself: in some cases greater, because of the need for a standard of quality approaching 100 per cent.

Prices to farmers. The extent and rate of development of alternative crops appears to have been largely decided by the attractiveness of the market prices. Alternative crops have not usually yielded a return to the farmers comparable with that which they received for cocoa, and the considerable attention to the development of additional export industries has given small results. A small measure of assistance given to a promising industry might aid its development materially.

Local food produce. Except for recording produce movements at convenient places such as ferries, and estimating quantities sold in certain native markets, there has been little interference with local food supplies in normal times. During the war market prices are controlled under the administration of a Director of Supplies. Attention to the distribution of food supplies is also necessary.

Savanna produce. As a general rule the stimulation of food-crop production is best confined to the savanna areas, which cannot grow cocoa, and not extended to the closed forest area, in which there should be as small an area of open fields as possible. In the present emergency however, an increase in the forest area is justified in order to reduce transport requirements.

General. There are several dormant issues affecting the cocoa industry; these include the provision of a cocoa-butter-fat factory, the provision of storage on Accra Beach, and the introduction of a marketing scheme on the lines recommended by the 1938 Cocoa Commission

Subjects that require consideration in normal times include the provision of a comprehensive inspection scheme covered by an inspection fee of one penny per bag, the restoration of pre-sale inspection, the licensing of buyers and of buying stations, the dissemination of price information amongst farmers, and the provision of crop forecasts.

Land-planning

Forest reserves. In the forest area the first essential for the preservation of a wet tropical climate is the provision of adequate Forest Reserves. Their use to protect existing cocoa, which occupies less than one-fifth of the forest area, has already been emphasized. They also benefit the farming community in many ways.

Land-planning in the forest area. Mention has already been made that the 1938 Cocoa Commission considered that the future of the cocoa industry would largely depend on the measures taken to control development. Forest Reserves occupy less than one-quarter of the forest area and require to be supplemented by a sufficiency of trees and of closed woods adequately dispersed throughout. Regular surveys require to be made in order to record the amount of land under bearing cocoa, in food farms with or without young cocoa in secondary bush, and in village clearings with a view to the adoption of measures for controlling the use of land. Aerial surveys would probably be most useful for this purpose. Some measures have already been adopted. In Ashanti the Native Divisional Authorities have made rules forbidding the cutting down of forest for planting new cocoa farms; these rules have resulted in curtailment of this practice. In the Eastern Province cocoa farms are being reafforested by planting shade-trees and shelter-belts under a cocoa-rejuvenation scheme. The Forestry Department has made considerable progress in partitioning the forest area by means of shelter-belt reserves. Unfortunately, there is little experimental evidence to assist in designing land-planning measures; even the effect on humidity and temperature of clearing forest is not known exactly. Consequently, little progress can be confidently made in regulating the use of land until adequate research work has been concluded. The problem is one which the Forestry Department would be best able to solve, although the Agricultural Department could give material assistance. The continued prosperity of the cocoa industry, the planned development of the western part of the forest area, and the rectification of the mistakes made in previous development depend to a considerable extent on the adoption of a co-ordinated programme of survey and research with a view to utilizing the land to the best advantage. The difficulties of confining swollen-shoot disease to its outbreak-centres in the Eastern Province have brought into prominence the foresight of the Forestry Department in planning shelter-belt reserves.

Land-planning in savanna areas. In the savanna areas there are large tracts where the population is scanty and the land undeveloped. Annual fires sweep over them causing soil erosion, fertility-exhaustion, and deterioration of the vegetation: some areas are so denuded that the land cannot be reclaimed for farming. Some consider that the loss is

so great that measures to prohibit burning would be justified. The development of an area with fire-breaks and shelter-belts might prove to be beneficial. Surveys and research would determine the advisability and practicability of such measures.

Soil conservation. On the farm the best method of preventing erosion is to use good farming practices; on wild grazing land, to prevent fires and so encourage a good vegetative cover. Soil erosion is also caused by roads and drains, and the adoption of soil-conservation measures is necessary. There is no overstocking by cattle at present, but, where an increasing cattle population enjoys uncontrolled communal grazing, measures should be adopted to control grazing before soil erosion becomes serious.

Agricultural Education and Instruction

The training of children in agriculture is a function of educational institutions, e.g. Achimota College and Government Schools, but the instruction of farmers is a function of the Agricultural Department. Instruction has to be preceded by co-ordinated research and survey, in order to determine the needs of the farmer, and to devise improvements that are not only good in themselves but have a good prospect of appealing to the farmer. The adoption of an improved practice by a progressive farmer is usually more effective propaganda than a demonstration farm. A proposal that is not in keeping with local custom or prejudice will have little chance of adoption and would be liable to prejudice the success of a subsequent sound proposal. The adoption of improvements by farmers is the final objective of the Department of Agriculture, whose activities all lead to that end. Consequently, the provision of an adequate extension staff of agricultural officers and the posting of them to a district for a period long enough for them to get to know the farms, the farming methods, and environmental conditions both physical and social, is essential if the confidence of the Chiefs and farming community is to be secured, collaboration with other welfare services maintained, and agriculture successfully developed.

Agricultural Policy

1. *Food farming.*—The protection and improvement of the production of local food supplies, both crops and live stock, and the development of food farming in the northern and coastal savanna areas, and at the same time the development and introduction of systems and methods of farming by the use of which soil fertility will be maintained.

The means by which these main objects will be accomplished are:

Animal diseases. The control of animal diseases, especially rinderpest (Animal Health Department).

Mixed farming, use of farmyard manure, ploughing. The extension of mixed-farming systems of crop and animal husbandry in the northern and coastal savannah areas wherever cattle can be kept in health, especially by encouraging the making and use of farmyard manure, and later by assisting 'mixed' farmers to use cattle-drawn ploughs and cultivators.

Cattle-breeding. The breeding and distribution of improved lines of cattle suitably resistant to trypanosomiasis and suited to local farming conditions (Animal Health Department).

Crop-breeding. The breeding and distribution of improved strains of crops, and new food crops, suited to local farming conditions.

Other improvements in food farming. The use of more efficient methods of crop and stock management, cultivation and preparation for market, especially in connexion with the control of food-crop diseases, crop rotations, cultivation methods, farm implements, composting and green manuring, pasture improvement, cattle suitable for mixed farming, breeding and feeding of small live stock, cattle nutrition in relation to health, supplementary cattle-feed, stall feeding, prevention of soil wash in arable farms, fruit-growing, and vegetable-growing.

Increased production. The greater production of beef, rice, beans, mutton, pork, poultry products, sugar-cane, fruit, and vegetables, and consequent less dependence on imported supplies especially desirable in time of war, improvements in nutrition and a sufficient increase in supplies for an increasing population.

Food scarcity. The improvement of food supplies in the North Mamprussi area where food scarcity periodically occurs.

Human nutrition. The improvement of food supplies in the light of diet deficiencies (Medical Department).

Grass fires. The control of grass-burning in farming areas.

Communications, water-supplies, tsetse clearing. The extension of farming to thinly populated and undeveloped areas with the aid, according to local needs, of the provision of roads, communications, and market places, the improvement of water supplies for both the human and cattle population (Geological Department), and the control of tsetse flies (Medical Department).

Forest food-farming systems. The development of systems of farming in the forest area, and adjacent areas where cattle cannot be kept in health, by the use of which soil fertility will be maintained.

2. *Cocoa production.*—The protection of the production of cocoa and the improvement of cocoa-farming, including the preparation of good-quality cocoa, with a view to maintaining the present annual output, and at the same time the development of measures and methods for the maintenance of those forest conditions of fertile soil and humid climate under which cocoa thrives.

The means by which these main objects will be accomplished are:

Forest reserves. The protection of existing cocoa by the adequate provision of Forest Reserves (Forestry Department).

Swollen-shoot disease. The control of swollen-shoot disease and the development of measures and methods by which the spread of it will be delayed and the incidence of it confined to the present outbreak centres.

Sahlbergella pest. The control of Sahlbergella pest, if found possible or practicable, by spraying, cultural methods, or biological means.

Other diseases and pests. The control of other diseases and pests.

Cocoa-breeding. The breeding of improved strains of cocoa that are resistant to diseases and pests, especially swollen-shoot disease, and most suited to local conditions of soil and climate, with a view to distribution to farmers.

Shade and shelter. The protection of cocoa farms and cocoa areas by the provision of trees for shade and shelter-belts.

Other improvements in cocoa cultivation. The use of more efficient methods of cultivation, soil treatment and drainage, care of environment, lateral protection, overhead shade, care of the cocoa tree, pruning and other treatment by which cocoa can be kept healthy, productivity maintained, longevity increased, moribund cocoa rejuvenated, and soil fertility preserved.

Cocoa planting. See under section 5, Land-planning.

Systems of cocoa-farming. The development of rotations in which cocoa occupies the land most or all of the time and the land is maintained in a state of fertility.

Cocoa establishment. The use of improved methods of establishing cocoa and improved strains of cocoa in forest and in old cocoa.

3. *Other crops and produce.*—The development of other crops in the forest and coastal areas for export and other produce for local use.

The means by which these main objects will be accomplished are:

Citrus-lime products. The use of more efficient methods of cultivation and the development of processing and export by private enterprise.

Kola nuts. No special measures at present.

Rubber. No special measures at present.

Oil palm. The use of improved types and methods from the Nigerian research scheme, and the prevention of felling for palm wine or the replacement of felled palms in accordance with by-laws by native states.

Coconut. The extension of planting on sandy soils along the coast and also inland in the Axim area, the control of a killing disease at Weh in the Keta area, and the maintenance of productivity in coconut plantations.

Bananas. The control of Panama Disease and, if possible, the eradication of it; the use of more efficient methods of planting and cultivation in order to fill the shipping space available and to maintain the size of the industry on this basis; and an economic study of planting methods and conditions with a view to determining the prospects for expansion when shipping facilities can be made available.

Coffee. No special measures at present.

Cotton. The maintenance of a cottage industry.

Grapefruit. The continuance of experimental work relating to the production and marketing of commercially seedless grapefruit with a view to the eventual establishment of a local trade in fresh and canned fruit and a small export of fresh fruit.

Oranges. The continuance of experimental work leading to the eventual establishment, if possible, of a small overseas trade.

Citrus-fruit moths. The control of citrus fruit-piercing moths and the development of measures by which damaged fruit could be excluded from consignment (Colonial Development Fund grant on behalf of Gold Coast and Sierra Leone).

Cassava starch. Under investigation at present.

Shea. No special measures at present.

Tobacco. The use of improved seed and methods of production in selected areas. Issue of pure seed: Magnum Pryor and Bourbon.

Other crops. The development of possible new local or introduced crops or plants likely to be of value for local use or for export.

Other methods. The development of new methods and new processes likely to be of value to producers in this country.

Other diseases and pests. The protection of areas from other diseases and pests.

4. *Produce-marketing.*—The efficient marketing of good-quality cocoa, the efficient marketing of other produce for export and the improvement of the distribution of locally produced food supplies.

The means by which these main objects will be accomplished are:

(*a*) *Cocoa*

Cocoa control. The administration of the Cocoa Control Scheme.

Quality of cocoa. The maintenance and improvement of the quality of cocoa by the use of more efficient preparation and thorough drying, especially with the aid of Inspection Services.

Cocoa-marketing co-operative societies. The consolidation and gradual expansion of the work of cocoa-marketing societies under financial supervision with friendly guidance.

Cocoa destruction. The local use of cocoa which is not marketed overseas under the Cocoa Control Scheme and the disposal of the surplus by burning.

(*b*) *Produce other than cocoa and local foodstuffs*

Markets for produce. The provision of marketing services in the initial stages of the development of a new industry and the development of marketing by private enterprise.

Prices for produce. A continuous review of the prices paid to farmers with a view to assisting promising industries through difficult periods.

Quality of produce. The maintenance and improvement of the quality of produce by the use of efficient preparation with the aid of inspecting services, especially in the cases of copra, bananas, and citrus fruits.

Co-operative societies. The supervision and guidance of co-operative societies dealing with the marketing of copra, bananas, citrus, and coffee.

(*c*) *Local foodstuffs*

Local food produce. The improvement of the distribution of locally produced food supplies in relation to demand.

Savanna produce. The development of measures for increasing the export of foodstuffs from the savanna to the high forest and urban areas.

5. *Land-planning.*—The protection of undeveloped, neglected, or abandoned farming land against deterioration by the use of land-planning measures, involving the regulation of crop planting and, eventually, of cattle grazing.

The means by which this main object will be accomplished are:

Forest reserves. The general protection of the closed forest area by the provision of forest reserves so that those forest conditions of atmosphere and rainfall that suit the cultivation of cocoa and other tropical forest crops can be preserved (Forestry Department).

Land-planning in the forest area. The protection of the closed forest area by the development of land-planning measures designed to secure a sufficiency of high forest, perennial, and forest crops in relation to field crops and savanna vegetation, and to preserve the land and the conditions for agricultural use, regard being had to the value of forest-belts in delaying the spread of crop diseases and pests.

Land-planning in savanna areas. The general protection of the savanna areas by the control of grass-burning in sparsely populated or undeveloped areas where investigation shows that grass fires are causing deterioration of the soil or its fertility beyond recovery and could be controlled by practicable methods.

Soil conservation. The general use of measures for soil conservation in pasture or potential farming land.

6. *Agricultural education and instruction.*—The encouragement of general agricultural progress, the promotion of agricultural leadership, and the development of improvements in keeping with other social services, with African aims and aspirations, and with the march of Native Administration.

Progressive farmers. The encouragement of progressive farmers and their use as demonstrators and leaders.

Agricultural education. The training of Africans in scientific agriculture by educational institutions (in collaboration with Achimota College and Education Department).

Native administration. The development of agricultural services in co-ordination with all the welfare and social services and especially in conformity with the policy of Native Administration.

Agricultural extension. The retention of the good features of farming as practised at present.

The incorporation of improvements gradually and only after full investigation not only by agricultural experiment and survey but also in the light of a comprehensive examination of the psychological and social effects of the changes contemplated.

The dissemination of agricultural knowledge by an agricultural field staff, especially African staff, who get among the people and become regarded as approachable friendly advisers to the Chiefs and leading farmers in all matters relating to agriculture.

* * * * *

Since the foregoing was written the progress of the war and events arising therefrom have caused certain modifications to be introduced

into agricultural policy which may be expected to have some permanent influence on future developments.

Thus in regard to food production, increasing shortages of imports of food from overseas have led to the intensification of measures to ensure an adequate supply of locally-produced foodstuffs for the population. This has entailed enhanced control over production combined with such measures as the establishment of guaranteed minimum prices for a number of food crops, e.g. rice, millets, groundnuts, pulses, shallots, and palm oil, the establishment of live-stock concentrations near large markets, and the development of supplies of fresh vegetables. Combined with this, departmental efforts have included the establishment of a pig farm to supply both animals for direct consumption and for breeding, and of smaller live-stock units at selected places; also to the development of two mixed-farming units and a stock farm under the native administration at Yendi.

There has been also considerable development in regulating the distribution of foodstuffs of local origin, whilst the production of honey, jams, marmalade, fruit juices, and beeswax for local consumption has been fostered. There has, in addition, been marked development in the production of tobacco.

Concurrently, the effects of the war have been to lessen the exports of cocoa, although the purchase of the crop by H.M. Government has been continued. There has been a considerable increase in the local consumption of cocoa as a food and also as a source of fat for soap-making, &c., although many thousands of tons of deteriorated cocoa have had to be burnt. Latterly the extraction of cocoa-butter for export has become of some importance. This has necessarily led to some diminution of departmental activity in other directions, but activities in regard to cocoa research have been maintained and extended particularly in relation to swollen-shoot disease, with the assistance of a grant from Colonial Research Funds.

The production of cocoa has declined somewhat during the war period, new planting has ceased, and operations have been handicapped by shortages of man-power; unfavourable seasons have played their part, while the influence of the capsid bug Sahlbergella and swollen-shoot disease have also contributed to the result. The rehabilitation of the industry to its former level of production must be a matter of prime importance in policy after the war.

Meantime attention has been devoted to certain matters of general import in regard to land-planning. It has become increasingly evident that in the Northern Territories soil erosion (mainly sheet erosion) is prevalent, and a definite and active policy for soil conservation is needed, which must be combined with the prevention of grass-burning and the introduction of mixed farming. Population transfer is indicated as desirable at some heavily populated points. Rules against grass-burning have already been introduced and active measures in other directions are in contemplation or have been undertaken.

Educational matters in regard to agriculture have also received a full share of attention, and proposals are under consideration for the develop-

ment of Bunsu Estate as a centre for agricultural education to include the training of agricultural staff and of teachers of rural science in schools, and the vocational training of prospective farmers.

During this period the work of many of the departmental staff has perforce been diverted from their normal lines of work, but with the resumption of peace they will once more become available for such duties. The lessons of the war point the way for many developments in the post-war period, and it is obviously important that the best features of the economy imposed by war should be incorporated as permanent features of agricultural policy in the future. It seems clear that a planned progressive policy of food farming and conservation of natural resources should replace the haphazard exploitation which has been visible in the past. This should serve to establish the rural economy of the Gold Coast on a sound foundation and enable self-sufficiency to be achieved in those products which can be economically produced in the Gold Coast; at the same time the territory would continue to produce a growing volume of exports of commodities of tropical origin which temperate countries cannot produce themselves but desire to import.

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STUDIES ON THE FATS OF THE BACON PIG WITH REFERENCE TO CARCASS QUALITY

1. IODINE VALUE OF THE BACK FAT UNDER DIFFERENT CONDITIONS OF FEEDING

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THE fat of the New Zealand bacon pig is usually hard and of good quality, owing to the general use of skim milk as a fattening ration [1, 2]. In Europe, America, and South Africa pigs with soft or oily carcasses have been reported [3, 4, 5].

The production of pigs with soft carcasses is attributed chiefly to the use of feeds containing more than 5 per cent. oil having an iodine value of 100 or more [1, 5, 6, 7]. On diets of very low fat-content (less than 0·5 per cent.) the fat of even young pigs is hard [8]. As the pig grows older, more and more fat is synthesized from carbohydrate and such fat is hard. If the soft dietary fat is not excessive in amount, the deposited fat becomes progressively harder with maturity. With rapid growth of the animal, more of the fat is synthesized from carbohydrate and less derived from direct assimilation. Hence, with feeds containing soft fats, pigs which make rapid gains are less likely to produce soft carcasses than those which grow more slowly [1, 5, 9, 10, 11, 12].

According to Lush *et al.* [13], fats from female pigs have, on the average, 1·7 higher iodine value than corresponding fats from male pigs. Similar observations have also been made by Johns [12]. The softness of pig fat is also influenced by temperature, the fats from pigs grown in summer being firmer than the fats from winter-grown pigs [10, 12]. According to Romyn [5], the Large Black breed has a tendency to produce soft fat.

Henriques and Hansen [14] suggest that the composition of the depot fats of animals is controlled by body-temperature, the iodine value of the fats from the various sites of the body decreasing with rise in temperature [15]. Callow [16, 17] offered the alternative hypothesis that the softness or iodine value of fat in different parts of the body is conditioned by the rate of growth. He showed that this explanation accounts for certain differences in iodine value which cannot be explained by variation in body-temperature, e.g. the outer layer of back fat, which must be at the same temperature throughout, has different iodine values at different parts of the body. Johns [12] provided further data in support of the growth-rate theory. According to McMeekan [6], although the growth-rate theory can explain increased saturation of fat with age and the differences in iodine value between the various types of fat deposited, it does not account very well for the initial and very significant increase in iodine value of all deposits between birth and 8 weeks.

Soft fats are disliked as they tend to give unsightly carcasses and cause extra losses during cooking [1]. Soft fats also lead to spoilage in bacon and particularly in hams, in which, owing to the long storage period, rancidity is likely to develop [11]. In cases of extreme rancidity, a yellow colour may appear in the fat [18]. A high quality of fat is thus necessary in frozen carcasses exported for the manufacture of bacon in Great Britain [1].

It has been generally held that hard fat is less likely to develop rancidity than soft fat because it contains less of the di- and polyethenoid acids which are responsible for the oxidative changes associated with rancidity [1, 2]. Rancidity in fat is, however, not merely a question of softness or of unsaturation as measured by iodine value. According to Lea [19], there are three factors in rancidity, (1) the tendency of a particular mixture of glycerides present to oxidize, (2) the activity of the natural antioxidants deposited with fat, and (3) the activity of the fat-oxidizing enzyme 'lipoxidase'. Small daily doses of cod-liver oil do not affect appreciably the iodine value or hardness of the carcass, yet the traces of highly unsaturated acids from cod-liver oil appear in the carcass fat and promote rancidity [9, 20, 21]. Barnicoat [22] found that with whale oil or low-grade fish meal fed in considerable quantity the fats of the pigs became soft and rancid. Other workers such as Lush *et al.* [13] also noted that dietary cod-liver oil tends to produce soft carcasses. On the other hand, Foot, Henry, Kon, and Mackintosh [23] found no gross defects in colour and firmness of the fat or in the suitability of the carcasses for bacon, even when as much as 2 per cent. cod-liver oil was fed up to the time of death. These workers do not, however, record peroxide or iodine values, nor do they discuss results of previous work.

Lea [19] found that pigs with higher growth-rates deposited harder fats with greater susceptibility to oxidation as compared with fats from pigs which grew more slowly. This was later verified by Johns [12], who reported that the differences in susceptibility to oxidation of the back fat of animals of different sexes appeared to be adequately accounted for by the theory that differences in the composition of the fat and tissue are due primarily to differences in the rate of deposition. Using animals fed on a diet of low fat-content, he found the greater the rate of deposition the harder the fat, but the greater also its susceptibility to oxidation. The antioxidants present in the feed may also affect the antioxidant-content of the tissues and thereby affect the susceptibility of the pig fat to oxidation.

Melting-points, refractive indices, and iodine values have been used as criteria for determining the hardness of pig fat. Hankins and Ellis [3] consider refractive index and iodine value superior to the melting-point. Hostetler, Halverson, and Sherwood [24], however, report that both melting-point and iodine value are better correlated with fat grade than is the refractive index. Recently, Hiner and Hankins [25] claimed that a penetrometer may be used for determining hardness of fatty tissue, correlation between the committee grade, penetrometer readings, and refractive index being equally high. Bolton and Baskett [26] have, however, found that where precise temperature-control is impracticable, the

iodine value is a more accurate index of firmness of bacon fat than the penetrometer value.

The iodine value is widely used for determining hardness of fat, but there is no agreement concerning the limiting iodine value for hard fat. Hankins and Ellis [3] set 63 as the average value for hard fat and 88 as the average for the softest grade. On the other hand, Romyn [5] stated that an iodine value above 60 is taken to represent an undesirable degree of softness in a bacon pig, a value of 64 being usually taken as the limit for firmness [27]. The iodine value has many limitations when applied to the determination of hardness, but the determination of fatty-acid composition and glyceride-structure is an almost impossible task where large numbers of samples are involved.

On a non-fatty diet, the pig fat is hard (iodine value 50–60) [1], and contains the saturated fatty acids—palmitic, stearic, with traces of myristic; the unsaturated fatty acids consisting of oleic with traces of palmitoleic acid. Linoleic, and highly unsaturated acids, C_{20} and C_{22} when present, are generally regarded as being derived entirely from ingested fats [28, 29].

Although the C_{20} and C_{22} highly unsaturated acids found in pig body fats may originate mainly from ingested fat, the large proportion of these acids always found in the liver fats [30] suggests the possibility, in certain cases at least, that some of the C_{20} and C_{22} highly unsaturated acids in the body fat may be of synthetic origin.

The majority of common pig foods of vegetable origin have fats containing oleic, linoleic, and linolenic acids [31]. The latter, however, is not appreciably assimilated by the pig [32].

Fish and, to a lesser extent, meat meals have fats containing highly unsaturated C_{20} and C_{22} acids. Assimilation of small proportions of these acids will produce a larger change in the iodine value of the deposited fat than assimilation of the same proportion of oleic or linoleic acids. In addition, these C_{20} and C_{22} acids differ from the unsaturated acids of plant origin in their susceptibility to oxidation [33]. Thus, a comparison of the properties of fats from pigs fed diets containing different fatty acids is not possible on the basis of iodine value alone.

Even in pigs fed wholly on plant materials, the iodine value is not wholly satisfactory as an index of the properties of the fat. Pigs fed peanuts or soya beans may deposit fat with low saturated fatty-acid content (14–26 per cent.) as compared with the normal (36–8 per cent.) [32]. On the other hand, pigs fed copra [34, 35] containing fat with more than 90 per cent. saturated acids yield fats with iodine value as low as 32·5.

The ratio of saturated acids to unsaturated acids and monoethenoid C_{18} acids to diethenoid C_{18} acids, also the presence of C_{20} and C_{22} highly unsaturated acids, all complicate the interpretation of results based on iodine value alone.

The effect of different feeds and the effect of restriction of feed on the iodine value of the back fat were studied using the back fats of Berkshire bacon pigs from the Ruakura herd (killed at approximately 200 lb. live weight).

TABLE 1. *Description of Groups used for Carcass-quality Studies in the 1938–9 Series*

(*a*) SPRING LITTERS

Group	*No. animals*	*Fattening ration**	*Rate of feeding*	*Growth-rate lb. per day*
D	3	Buttermilk	Full-fed	1·18
K	13	Buttermilk	Full-fed to 150–170 lb., then restricted 50–75%	1·03
E	3	Buttermilk	75% to 200 lb.	1·06
B	3	Buttermilk	75% to 170 lb., then 5 gall. and 2 lb. maize	1·04
G	7	Mixed meal†	Full-fed	1·57
I	7	Mixed meal†	Restricted to 75% of G	1·16
H	4	Skim milk and 1 lb. maize meal	Full-fed	1·39
J	5	Ditto	Restricted to 75% of H	1·03

(*b*) AUTUMN LITTERS

Group	*No. animals*	*Fattening ration*	*Rate of feeding*	*Winter ration*	*Growth-rate lb. per day*
L	6	Buttermilk	Full-fed	½ lb. of pumpkin and 1 lb. of maize, meat meal, and roots	1·59
M	7	Buttermilk	75%	1 lb. meat meal, bone meal, and pumpkin roots	1·28
F	4	Buttermilk	75% to 170 lb., then 7 gall. and 2 lb. pea-meal	1½ lb. maize	1·54
A	8	Buttermilk	Full-fed to 170 lb., then 75%	1 lb. maize, meat meal and 1 oz. cod-liver oil or horse oil	1·3
C	5	Mixed meal‡	Heavy restriction	1 lb. maize and roots	0·93

* In Groups G, I, H, and J the sub-groups of stied and paddocked animals were in each case combined, the effect of pasture on the iodine value of the fat being practically insignificant. Throughout the remaining experiments the pigs were generally not stied but had access to pasture, the effect of which on the iodine value of the fat has been disregarded.

† Barley meal 4 lb., maize 2 lb., pollard 1 lb., meat meal ½ lb., and 1 gallon skim milk per pig per day.

‡ Barley meal 3 lb., pea-meal 1 lb., and meat meal ½ lb.

Experimental

On the basis of the refractive index, Ellis and Isbell [36] have shown that the back fat is representative of the entire adipose tissue of the pig. In this work, therefore, a thin strip (½ in.) was cut along the middle of the back extending from the shoulder to the tail. After dividing the strip along the connective tissue into inner and outer layers, these were

divided into four equal lengths. The strips were treated with boiling alcohol followed by mincing and extraction with petroleum ether (b.-pt. 40–60°). The extraction was facilitated by filtering, re-extracting, and pressing the insoluble residue until fat-free. After distilling the solvent from the filtered extract the fat was dried to constant weight *in vacuo* at 100° C. The iodine values of the extracted fats were determined by Wij's method (1 hour).

In the first series of investigations there were 22 groups of feeding experiments each consisting of approximately 10 pigs. Only 79 carcasses were available for chemical investigation, and, in order to obtain statistically significant results, combinations of similar groups were made to give the groups indicated in Table 1.

In Table 2 the mean iodine values and standard error are given for each group, the iodine values for individual strips being omitted to save space. To illustrate more clearly the results of statistical analysis, the iodine values are set out in descending order of magnitude.

The iodine values of the outer and inner layers follow the same general trend, the former generally being 2·9–4·8 units higher than the latter. In group F the iodine value of the outer back fat is 6 units higher than that of the inner back.

The unsupplemented buttermilk groups yielded fats whose iodine values were lower than those of fats from the remaining groups. The difference in iodine value between group H (full-fed skim milk and maize meal) and these groups was not, however, significant except in group D (full-fed buttermilk) in which the iodine value of the outer back layer was significantly lower than was found for group H. Within the unsupplemented buttermilk groups, the outer back fats varied over a range of 2·06 units and the inner-back fat over a range of 3·50 units. With the exception of group A and groups M and E (autumn and spring litters respectively), which showed a significant softening (in the inner-back fat only) as compared with group D, full-fed spring litters, the fats from the unsupplemented milk-fed pigs showed no significant differences in iodine value.

Group C fattened on mixed meals after a store period of 6 months produced fat of the highest iodine value; the result, however, was not significantly different from that of the 75 per cent. restricted maize diet. The meal consisted of meat meal, pea-meal, and barley meal in the proportion 1 : 2 : 6, and was fed at the rate of 3 lb. per day for 6 weeks, followed by 4 lb. per pig per day for the remainder of the trial. This experiment showed the effect of heavy restriction on a fattening ration of a type reputed to give soft fat. Although on the average the back fats would not be classified as soft, fats from two of the pigs which made the slowest gains had iodine values which fell outside the accepted limits for hard fat.

Although pigs fed maize meal (groups H and J) showed a significant softening of the fat in the restricted as compared with the full-fed groups, this effect was not observed in the groups (G and I) fed mixed meals. In the case of the outer back fats the probability of the difference in iodine value between the full-fed and restricted groups being due to chance was, however, only 5·4 per cent.

TABLE 2. *Average Iodine Numbers of Back Fats and Significance of Differences between Groups*

(*a*) OUTER BACK FAT

Group	*Mean I.V.*	*S.E. of mean I.V.*	*Significance of differences between means**												*Remarks*
			D	*K*	*L*	*B*	*E*	*M*	*H*	*A*	*F*	*G*	*I*	*J*	
C	65·22	1·27	HS	HS	HS	HS	HS	HS	HS	HS	S	HS	N	N	Mixed meal, heavy restriction. W.S.†
J	62·37	1·28	HS	HS	HS	HS	S	HS	S	N	N	N	N		Skim milk+maize meal, restricted to 75% of H. S.L.‡
I	62·26	0·78	HS	HS	HS	HS	HS	HS	HS	S	N	N			Mixed meal, restricted to 75% of G. S.L.
G	60·30	0·48	HS	HS	HS	HS	HS	HS	N	N	N				Mixed meal, full-fed. S.L.
F	60·10	0·84	HS	HS	HS	S	S	S	N	N					Buttermilk, 75%, restricted to 170 lb., then 7 gall. and 2 lb. pea-meal. W.S.
A	59·32	0·69	HS	HS	S	S	S	S	N						Buttermilk, full-fed to 170 lb., then restricted to 75%. W.S. Fed cod-liver oil or horse oil
H	57·98	0·90	S	N	N	N	N	N							Skim milk+1 lb. maize meal, full-fed. S.L.
M	57·10	0·67	N	N	N	N	N								Buttermilk, restricted to 75%. W.S.
E	57·03	0·73	N	N	N	N									Buttermilk, restricted to 75%. S.L.
B	56·45	0·60	N	N	N										Buttermilk, restricted to 75% to 170 lb., then 5 gall. and 2 lb. maize. S.L.
L	56·11	0·86	N	N											Buttermilk, full-fed. W.S.
K	55·93	0·55	N												Buttermilk, full-fed 150–70 lb., then restricted 50–75%. S.L.
D	55·04	0·76													Buttermilk, full-fed. S.L.

(*b*) Inner Back Fat

C	60·57	1·01	HS	HS	HS	HS	HS	HS	HS	HS	HS	HS	S	N	Mixed meal, heavy restriction. W.S.†
J	58·55	1·26	HS	HS	HS	HS	HS	HS	HS	S	S	N	N		Skim milk+maize meal, restricted to 75% of H. S.L.‡
I	57·54	0·72	HS	HS	HS	HS	HS	HS	HS	S	S	N			Mixed meal, restricted to 75% of G. S.L.
G	56·29	0·58	HS	HS	HS	HS	HS	HS	HS	N	N				Mixed meal, full-fed. S.L.
F	54·09	0·84	S	N	N	N	N	N	N	N					Buttermilk, 75% restricted to 170 lb., then 7 gall. and 2 lb. pea-meal. W.S.
A	54·77	0·78	HS	S	S	S	N	N	N						Buttermilk, full-fed to 170 lb., then restricted to 75%. W.S. Fed cod-liver oil or horse oil
H	53·16	0·74	N	N	N	N	N	N							Skim milk+1 lb. maize meal, full-fed. S.L.
M	53·42	0·66	S	N	N	N	N								Buttermilk, restricted to 75%. W.S.
E	54·15	1·02	S	N	N	N									Buttermilk, restricted to 75%. S.L.
B	52·51	0·39	N	N	N										Buttermilk, restricted to 75% to 170 lb., then 5 gall. and 2 lb. maize. S.L.
L	52·47	0·56	N	N											Buttermilk, full-fed. W.S.
K	52·37	0·56	N												Buttermilk, full-fed 150–70 lb., then restricted 50–75%. S.L.
D	50·65	0·70													Buttermilk, full-fed. S.L.

* Where the odds of the difference in means being due to chance are less than 19 to 1 the result is classed as 'not significant' (N); where the odds lie between 19 to 1 and 99 to 1, the result is classed as 'significant' (S); and where the odds are greater than 99 to 1, the result is designated as 'highly significant' (HS).

† W.S. Used to indicate Winter Stores in this and in subsequent tables.

‡ S.L. Used to indicate Spring Litters in this and in subsequent tables.

In the buttermilk groups, the addition of 1 oz. of cod-liver oil or horse oil during the store period (group A) resulted in a significant increase in iodine value, especially in the outer back layer,* and the addition of 2 lb. of pea-meal towards the end of the fattening period (group F) also resulted in significant softening, but in this case the effect was confined chiefly to the outer layer. The addition of 2 lb. of maize

TABLE 3. *Description of Groups used for Carcass-quality Studies, 1939–40 Series*

(*a*) SPRING LITTERS

Group	*No. animals*	*Fattening ration*	*Rate of feeding*	*Daily gain while fattening*
27	9	Skim milk	Full-fed	1·30
28	12	Skim milk	Full-fed to 150 lb., then 6 gall., and after 6 weeks altered to 4½ gall. to 200 lb.	1·11
32	10	Buttermilk	Full-fed to 150 lb., then 5¼ gall. to 200 lb.	0·95
33	6	Buttermilk	Full-fed to 150 lb., then 4¼ gall. to 200 lb.	0·93
31	5	Buttermilk + 1 lb. copra† per pig per day	Full-fed to 140 lb., then 75% buttermilk to 180 lb.	1·11

(*b*) AUTUMN LITTERS

Group	*No. animals*	*Fattening ration*	*Rate of feeding*	*Winter ration*	*Daily gain while fattening*
21	11	Buttermilk	Full-fed	Swedes and ½ lb. meat meal	1·88
20	12	Buttermilk	Full-fed to 150 lb., then 6 gall. to 200 lb.	Pumpkins, swedes + ½ lb. meat meal	1·46
22	10	Buttermilk	Ditto	Swedes and ½ lb. meat meal	1·55
25	12	Buttermilk	Full-fed	1·25–1·75 lb. maize meal + ½ lb. meat meal with 1 oz. cod-liver oil or horse oil	1·92
26	10	Buttermilk	Full-fed to 150 lb., then 6 gall. to 200 lb.	1·25–1·75 lb. maize meal + ½ lb. meat meal with 1 oz. cod-liver oil or horse oil	1·45

* The object of this experiment was to determine whether or not cod-liver oil effected any improvement, horse oil (iodine value 103) being used as a control. Both cod-liver-oil and horse-oil groups made similar gains. From inspection of the iodine values, cod-liver oil and horse oil were equally softening.

† The copra contained 63 per cent. fat.

TABLE 4. *Average Iodine Numbers of Back Fats and Significance of Differences between Groups in the 1939–40 Series*

(*a*) OUTER BACK FAT

Group	Mean I.V.	S.E. of Mean I.V.	31	32	33	27	22	21	26	28	25	Remarks
20	60·63	0·66	HS	HS	HS	HS	HS	HS	HS	HS	S	Full-fed buttermilk to 150 lb., then 6 gall. to 200 lb. W.S.
25	57·60	0·90	HS	HS	HS	S	N	N	N	N		Full-fed buttermilk, 1 oz. cod-liver or horse oil in winter. W.S.
28	57·48	0·44	HS	HS	HS	HS	S	HS	N			Full-fed buttermilk to 150 lb., then 6 gall. and subsequently 4½ gall. to 200 lb. S.L.
26	56·76	0·72	HS	HS	HS	N	N	N				Full-fed buttermilk to 150 lb., then 6 gall. to 200 lb. 1 oz. cod-liver oil or horse oil in winter. W.S.
21	55·71	0·34	HS	S	HS	N	N					Full-fed buttermilk. W.S.
22	55·44	0·68	HS	S	N	N						Full-fed buttermilk to 150 lb., then 6 gall. to 200 lb. W.S.
27	54·48	0·88	HS	N	N							Full-fed skim milk. S.L.
33	52·81	1·12	HS	N								Full-fed buttermilk to 150 lb., then 4½ gall. to 200 lb. S.L.
32	52·79	1·05	HS									Full-fed buttermilk to 150 lb., then 5½ gall. to 200 lb. S.L.
31	45·71	1·47										Buttermilk + 1 lb. copra per pig per day. Full-fed to 140 lb., then 75% buttermilk to 180 lb. S.L.

(*b*) INNER BACK FAT

20	56·27	0·59	HS	HS	HS	HS	HS	HS	HS	N	S	Full-fed buttermilk to 150 lb., then 6 gall. to 200 lb. W.S.
25	53·77	0·72	HS	HS	S	N	N	N	N	N		Full-fed buttermilk, 1 oz. cod-liver or horse oil in winter. W.S.
28	55·21	0·40	HS	HS	HS	HS	HS	HS	HS			Full-fed buttermilk to 150 lb., then 6 gall. and subsequently 4½ gall. to 200 lb. S.L.
26	52·23	0·56	HS	S	N	N	N	N				Full-fed buttermilk to 150 lb., then 6 gall. to 200 lb., 1 oz. cod-liver oil or horse oil in winter. W.S.
21	52·34	0·45	HS	S	N	N	N					Full-fed buttermilk. W.S.
22	52·82	0·69	HS	S	N	N						Full-fed buttermilk to 150 lb., then 6 gall. to 200 lb. W.S.
27	51·90	0·56	HS	N	N							Full-fed skim milk. S.L.
33	50·36	1·20	HS	N								Full-fed buttermilk to 150 lb., then 4½ gall. to 200 lb. S.L.
32	49·88	0·97	HS									Full-fed buttermilk to 150 lb., then 5½ gall. to 200 lb. S.L.
31	42·29	1·60										Buttermilk + 1 lb. copra per pig per day. Full-fed to 140 lb., then 75% buttermilk to 180 lb. S.L.

meal (group B) to the buttermilk diet towards the end of the fattening period was not found to affect significantly the firmness of the fat.

In view of the relatively small numbers of animals available for study in the groups of the 1938–9 experiments, opportunity was taken in 1939–40 to repeat some of the previous work, and to examine the effect of copra, mostly on groups with 10–12 animals. Details of these groups are given in Tables 3 and 4.

Comparison (cf. Table 5) of the iodine values of the 1938–9 and 1939–40 series showed that, in most cases, similar groups in different years gave similar iodine values. Sometimes, however, similar groups showed significant differences. Possible reasons for these differences may include variations in (*a*) temperature, (*b*) feed, (*c*) feeding technique, and (*d*) individuality. Groups 20 and 22 received the same treatment at the same time, but differed significantly with respect to the iodine value of the back fat. The growth-rate of both of these groups was similar, but group 20 had 75 per cent. No. 1 grade and 25 per cent. No. 2 as compared with 25 and 75 per cent. respectively for group 22.

The pigs in group 20 were heavier (98–129 lb., mean 112 lb.) than those of group 22 (73–96 lb., mean 84 lb.) when fattening started, but this can hardly account for the increased iodine value, since, during the previous year, pigs from group M, with iodine value similar to that of group 22, were still heavier (mean 119 lb.) at the commencement of the fattening period. The outer back fat of group 20 was oily. More than half the rendered fat remained liquid even at room temperature (18° C.). A glass stirring rod $4 \times \frac{1}{4}$ in. allowed to sink under its own weight readily penetrated the fat from this group, but in the fats from the remaining unsupplemented milk-fed groups the penetration did not exceed $\frac{1}{4}$ in. Marked differences in relative hardness of fats of pigs from different litter mates, using identical feeding conditions, have been noted by Sinclair [10]. This factor of individuality may well explain the relatively high iodine values of group 20.

According to McMeekan [2, 37] differential growth-rate determines the composition of the carcass and is a factor in determining the iodine value of the depot fat. In groups 20 and 22, however, apart from the fact that the pigs in group 20 made rather better gains during the store period (0·41–0·61 lb. per day as compared with 0·17 to 0·38 lb. per day for pigs in group 22), there were no marked differences in rates of growth at any period during fattening. In any case, the possibility of differential growth being a contributory factor in the production of the relatively soft fat of the pigs in group 20, is unlikely, because restriction of the diet in the case of the unsupplemented milk-fed pigs was generally without significant effect on the iodine value of the back fat.

Thus although the growth-rate theory affords an explanation of variations in the iodine value of the different depots, it does not explain the apparently similar iodine values found for the back fats of pigs fed at different planes of nutrition with an unsupplemented milk diet. It may well be that in the case of pigs fed on a diet containing soft fats, e.g. maize meal, the higher iodine values of the depot fats of pigs fed on restricted as compared with a full-fed diet, are due to the fact that the

soft dietary fats comprise a greater proportion of the depot fat. The iodine values of the different depots of pigs on a fat-free diet may possibly be due to some factor unconnected with growth-rate or with temperature.

TABLE 5. *Comparisons between Iodine Values of Similar Groups in 1938–9 and 1939–40 Experiments*

	1938–9 *Series*				1939–40 *Series*					
		I.V.				*I.V.*			*Difference*	
Treatment	*Group*	*Outer*	*Inner*	*Daily gain in lb.*	*Group*	*Outer*	*Inner*	*Daily gain in lb.*	*Outer*	*Inner*
(*a*) SPRING LITTERS										
Full-fed buttermilk or skim milk	(D)	55·04	50·65	1·18	(27)	54·48	51·90	1·30	−0·56 (N)	+1·25 (N)
Full-fed buttermilk or skim milk to 150 lb., then moderately restricted diet	(K)	55·93	52·37	1·03	(28)	57·48	55·21	1·11	+1·55 (S)	+2·84 (HS)
(*b*) AUTUMN LITTERS										
Full-fed buttermilk	(L)	56·11	52·47	1·59	(21)	55·71	52·34	1·88	−0·40 (N)	−0·13 (N)
Restricted	(M)	57·10	53·42	1·28	(22)	55·44	52·82	1·55	−1·66 (N)	−0·60 (N)
(*c*) AUTUMN LITTERS RECEIVING 1 OZ. COD-LIVER OIL OR HORSE OIL PER DAY DURING THE STORE PERIOD										
Group A. Full-fed buttermilk, then restricted to 75%	(A)	59·32	54·77	1·30	(25)	57·60	53·77	1·92	−1·72 (N)	−1·00 (N)
Group 25. Full-fed										
Group 26. Full-fed to 150 lb., then 6 gall. to 200 lb.					(26)	56·76	52·23	1·45	−2·56 (S)	−2·54 (S)

In the two consecutive years the spring litters D and 27, full-fed on buttermilk or skim milk, yielded back fats of similar iodine values (Table 5). The 1939–40 groups (28, 32, 33, Table 4) receiving restricted diets varied from 4·69 to 5·33 units for outer and inner back fats respectively. Group 28 had iodine values significantly higher than either those obtained from a similar group 32 during the same year or from a similar group K during the previous year. Despite the variability of these groups of the 1939–40 series, the average iodine values for both years agreed closely. In the autumn litters, apart from the high iodine values of group 20, the full-fed and restricted buttermilk groups showed excellent agreement with the results for the previous year. The small observed effect of dietary restriction on the iodine value was not significant. Allowing for variability of the animals, all the data so far obtained

suggest that restriction of the skim-milk or buttermilk diet has little, if any, effect on the iodine value of the back fat.

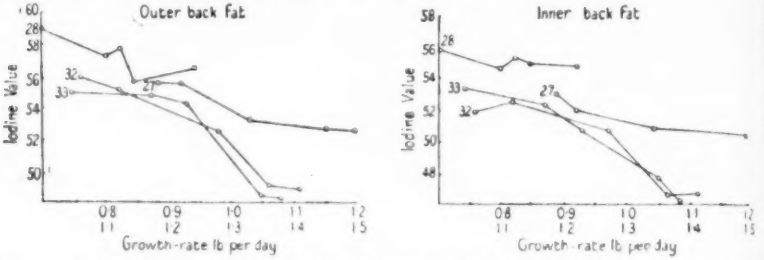

FIG. 1. Spring litters fed skim milk or buttermilk. Top line lb. per day refers to groups 32 and 33. Bottom line refers to groups 27 and 28.

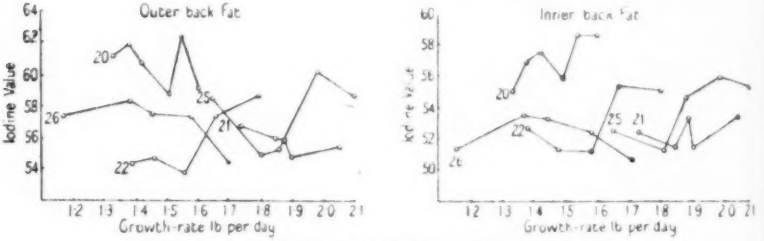

FIG. 2. Autumn litters fed skim milk or buttermilk.

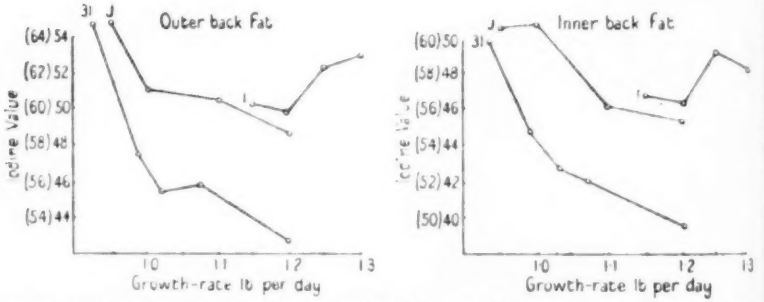

FIG. 3. Spring litters. Group 31 restricted buttermilk + 0·75 lb. copra per pig per day. Group I mixed meals. Group J restricted skim milk + 0·75 lb. maize per pig per day. Figures in brackets apply to groups I and J.

Comparison of the back-fat iodine values of groups receiving cod-liver oil or horse oil during the winter store-period showed no significant differences with respect to group A (1938–9 series) and group 25 (1939–40 series). In group A and group 26, however, there was a significant difference between consecutive years. The 1938–9 groups showed that there was a significant increase in iodine value on feeding cod-liver oil, but in the 1939–40 group the increase in iodine value of the cod-liver-oil group was not significant.

Effect of growth-rate on iodine value.—When the rate of growth is fast, more fat is synthesized from carbohydrate and less derived by direct assimilation than when the rate is slow. On a non-fatty diet, provided the synthetic fat has the same composition irrespective of the rate of deposition, the rate of growth would not be expected to have any effect on the iodine value of the back fat. This is exemplified by the autumn litters receiving skim milk or buttermilk only (groups 21 full-fed, 20 and 22 restricted); in fact, group 22 appears to indicate the opposite effect (cf. Fig. 2). Groups A, 25, and 26, which had received cod-liver oil during the winter store-period, also showed no marked tendency towards firmer fat in the fast-growing animals. The spring litters receiving skim milk or buttermilk showed a decided tendency, which was especially marked with the slower-growing groups 32 and 33, to produce harder fat when rate of growth was fast (Fig. 1). The apparent difference between the spring and autumn litters with regard to the effect of rate of growth on the iodine value cannot at present be explained.

The animals from the full-fed maize-meal (H) and mixed-meal (G) groups showed very small (*c.* 5 per cent.) variations in rate of growth. Much larger variations were observed for animals fed restricted mixed-meal and maize-meal diets (Fig. 3). The restricted mixed-meal groups gave irregular values showing little or no connexion between rate of growth and iodine value. The restricted maize-meal groups, on the other hand, showed a marked increase in iodine value with decreasing rate of growth.

The most decisive results were given by the copra-fed animals (Fig. 3). In accordance with the generally accepted idea that fast-growing animals receive less fat from the diet and more fat from carbohydrate sources than slow-growing animals, one would expect a tendency for the slower growing animals to deposit more of the copra fat than the faster-growing animals; the former should, therefore, have carcasses containing more coconut fat and have lower iodine values than the faster-growing animals.

The fact that the lowest iodine values were 10 units lower than those obtained from the back fat of pigs fed skim milk or other diets in which fat is practically absent, e.g. Brewers' rice [36], is in accordance with the idea that coconut fat had been assimilated. Contrary to the accepted idea with regard to unsaturated fat, it may be possible that dietary saturated fats are deposited to a greater extent by fast-growing pigs than by those which grow more slowly. Alternatively, the lower saturated fatty-acid components of coconut fat are more completely eliminated from the carcass in the slower-growing pigs. Although previous experimental evidence indicates that the dietary fatty acids below lauric acid are not readily retained in the depot fats of the rat [38], there are indications that such acids affect the degree of unsaturation of the deposited fats. For instance, Eckstein [39] found that tricaproin fed to rats increased the proportions of saturated fatty acids without altering significantly the saponification value.

Effect of sex on iodine value.—On the average, the outer back and

inner back fats of the sows were respectively 0·41 and 0·32 units higher than the corresponding values for the barrows, in agreement with the observations of previous workers [12, 13]. The differences, however, when examined statistically were not significant, as were those in Johns's observations [12], using small numbers of animals.

TABLE 6. *Mean Sectional Iodine Values*

(Figures in brackets indicate deviation from mean iodine value)

		Outer back fat					*Inner back fat*				
			Section					*Section*			
Group	*Type*	*Average whole strip*	1 *Head*	2	3	4 *Tail*	*Average whole strip*	1 *Head*	2	3	4 *Tail*
C	B	65·1	68·0 (+2·9)	67·6 (+2·5)	64·3 (−0·8)	60·4 (−4·7)	A 60·1	65·4 (+5·3)	58·0 (−2·1)	58·4 (−1·7)	58·6 (−1·5)
20	D	61·0	63·1 (+2·1)	61·5 (+0·5)	58·8 (−2·2)	60·6 (−0·4)	A 56·3	57·4 (+1·1)	55·8 (−0·5)	55·4 (−0·9)	56·8 (+0·5)
G	B	60·2	62·0 (+1·8)	60·3 (+0·1)	59·7 (−0·5)	58·8 (−1·4)	A 56·4	57·3 (+0·9)	55·2 (−1·2)	56·4 (0·0)	56·8 (+0·2)
F	B	60·1	62·4 (+2·3)	60·5 (+0·4)	59·2 (−0·9)	58·3 (−1·8)	A 54·8	55·5 (+0·7)	53·8 (−1·0)	53·9 (−0·9)	56·2 (+1·4)
A	B	59·4	62·4 (+3·0)	59·7 (+0·3)	58·8 (−0·6)	56·5 (−2·9)	A 55·0	57·7 (+2·7)	52·7 (−2·3)	53·8 (−1·2)	55·8 (+0·8)
22	C	58·1	59·7 (+1·6)	56·1 (−2·0)	58·7 (+0·6)	57·9 (−0·2)	A 55·3	55·0 (−0·3)	55·5 (+0·2)	54·5 (−0·7)	56·2 (+0·9)
E	B	57·1	59·5 (+2·4)	56·8 (−0·3)	56·9 (−0·2)	55·3 (−1·8)	A 54·2	56·5 (+2·3)	52·5 (−1·7)	53·1 (−1·1)	54·7 (+0·5)
B	B	56·5	57·9 (+1·4)	56·0 (−0·5)	56·9 (+0·4)	55·2 (−1·3)	A 52·6	53·3 (+0·7)	52·1 (−0·5)	52·5 (−0·1)	52·5 (−0·1)
K	C	56·0	57·2 (+1·2)	54·8 (−1·2)	56·4 (+0·4)	55·7 (−0·3)	A 52·4	53·2 (+0·8)	52·1 (−0·3)	52·0 (−0·4)	52·4 (0·0)
21	A	55·8	58·2 (+2·4)	54·5 (−1·3)	54·4 (−1·4)	56·2 (+0·4)	A 52·9	55·8 (+2·9)	51·5 (−1·4)	51·6 (−1·3)	52·6 (−0·3)
25	D	55·5	57·6 (+2·1)	55·0 (−0·5)	54·5 (−1·0)	54·8 (−0·7)	A 52·7	55·3 (+2·6)	50·6 (−2·1)	51·3 (−1·4)	53·6 (+0·9)
D	A	54·1	56·6 (+1·7)	54·3 (−0·6)	54·1 (−0·8)	54·5 (−0·4)	A 50·8	50·9 (+0·1)	49·4 (−1·4)	51·2 (+0·4)	51·6 (+0·8)
Deviation from mean iodine value for all groups			(+2·1)	(−0·2)	(−0·6)	(−1·3)		(+1·6)	(−1·2)	(−0·8)	(+0·4)

For convenience, the back fats have been classified into four types as follows:

	Outer Back	*Inner Back*
Type A. Those groups in which the iodine value of the 4th section is equal to or greater than that of the 2nd and 3rd.	2	12
Type B. Those groups in which the iodine value of the 4th section is less than the 2nd or 3rd.	6	..
Type C. Those groups in which the iodine value of the 3rd section is greater than that of the 2nd or 4th.	2	..
Type D. Those groups in which the iodine value of the 2nd section is greater than that of the 3rd or 4th section.	2	..

Mean sectional iodine values.—In the growth of the pig, deposition of fat is greatest nearest the head, less in the posterior of the back, and least where the loin region starts. Callow [16] has found a variation in iodine value of subcutaneous fat along the back. Using pigs at bacon weight, Johns [12] showed that the iodine and thiocyanogen values of the inner back fat follow the gradation in thickness of fat and hence its rate of deposition, being greatest in the head region, least near the loin, and intermediate at the posterior [40].

In Table 6 are given the mean iodine values obtained in the present investigations for each section in those groups where the inner and

outer layers have been divided into four equal lengths. As the weights of the sections were unequal, the mean iodine values for the groups deviate slightly from the average sectional values. In two groups (22 and 25), three only of the samples had been subdivided into four lengths, so that the mean iodine values given in Table 6 are considerably different from the mean weighted iodine value for the whole group.

The results in Table 6 show that the typical outer back fat contains progressively harder fat (lower iodine value) in each of the sections from the head to the tail, but, in all cases observed, the tail or fourth section of the inner back fat is relatively softer than the two middle sections. The differences in the gradient of iodine value with respect to the inner and outer layers may be related to the relative growth-rates along the back (Table 7). In the outer layer the fourth section contains the greatest amount of fat and typically the lowest iodine value. In the

TABLE 7. *Mean Percentage of Total Fat in each Section*

	Section			
	1	2	3	4
Outer back . .	25·32 ± 0·81*	25·04 ± 0·61*	21·94 ± 0·55*	27·70 ± 0·67*
Inner back . .	27·34 ± 0·95*	34·67 ± 0·66*	21·81 ± 0·60*	16·18 ± 0·80*

* Standard error of the mean.

inner layer the fourth section contains the least weight of fat and the iodine value is higher than in the second or third sections. The greatest deposition of fat in the inner layer occurs in the second section, which also has typically the lowest iodine value. Allowing for the fact that the fat initially laid down is relatively soft and confined mainly to the head section [16], the results in general are consistent with the theory that the iodine value is related to the rate of deposition of the fat.

Relation between grade and iodine values.—The heavily restricted mixed-meal diet group C produced carcasses which could not all be classified as hard (the iodine value of the back fat exceeding 64 in some cases), but the percentage first-grade pigs (92) based on measurements of back-fat thickness, was the highest of all groups examined. In the maize-meal groups, restriction of the diet increased the percentage of grade 1 pigs from 57 to 83, but raised the iodine value of the fat. The fat from at least two of the pigs in the restricted group could not be classified as hard, although the full-fed pigs all produced firm fat. In the mixed-meal groups (spring litters), restriction of the diet resulted in an increase of first-grade pigs from 58 to 86 per cent. without significant increase in iodine value. The copra-fed pigs yielded by far the firmest fat, but a low percentage (27) of first-grade pigs. With the exception of group 20, the fats of the remaining skim-milk or buttermilk-fed groups were, on the whole, of excellent quality in respect to firmness. Group 20 included a few pigs the iodine values of whose fat approached the upper limit for hard fat. The fats of this group, in general, if not classifiable as soft, could not be regarded as having the optimum degree of firmness. The results with regard to grading in the

skim-milk or buttermilk groups were not regular. The full-fed groups of spring litters or winter stores generally yielded a lower percentage of first-grade carcasses (10–55) than the corresponding groups which had received restricted diets (48–83); the restriction in diet generally having no significant effect on the firmness of the fat.

Summary

1. Bacon pigs from spring or autumn litters fed skim-milk or buttermilk generally yielded carcasses with firm fats, restriction of the diet having little, if any, effect on the hardness.

2. The addition of 1 lb. of maize meal to a full-fed skim-milk diet throughout the fattening period, or the addition of 2 lb. maize meal to a restricted buttermilk diet towards the end of the fattening period, had no significant effect on the hardness. On a restricted skim-milk diet, however, the addition of 0·75 lb. maize meal throughout the fattening period resulted in a significant softening of the carcass.

3. The addition of 1 lb. of copra to the buttermilk diet resulted in a marked lowering (10 units) in iodine value of the back fat.

4. In autumn litters the addition of 2 lb. pea-meal to a restricted buttermilk diet towards the end of the fattening period, or the addition of 1 oz. cod-liver oil during the winter store-period, resulted in a small but significant increase in iodine value. In a subsequent experiment, however, feeding of 1 oz. cod-liver oil during the winter store-period had no significant effect.

5. The softest fats were produced from autumn litters fed on a heavily restricted diet of barley meal 3 lb., pea-meal 1 lb., and meat meal $\frac{1}{2}$ lb.

6. Though on diets tending to produce soft fats the softening is generally greater the slower the rate of growth, those copra-fed pigs which grew fastest showed the greatest hardening. The theory that the assimilation of dietary fat is greatest for the slowest-growing animals may need modification in the case of dietary fat containing fatty acids of low molecular weight.

7. Variations in iodine values along the back fat were consistent with the theory that the iodine value is related to the rate of deposition of the fat.

8. In pigs fed on milk unsupplemented, improved grading following restriction of diet was achieved without detriment to the hardness of the fat. The improved grading of pigs fed on skim milk and maize-meal, following a restricted diet, was associated with the production of softer fat.

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REFERENCES

1. Callow, Empire J. Expt. Agric., 1935, **3,** 80.
2. McMeekan, N.Z. J. Agric., 1937, **54,** 223.
3. Hankins and Ellis, U.S. Dept. Agric., 1926, Bull. No. 1407.
4. Jackson, J. Min. Agric., 1923, **30,** 261.
5. Romyn, Rhod. Agric. J., 1936, **33,** 474.
6. McMeekan, J. Agric. Sci., 1940, **30,** 276.
7. Anderson and Mendel, J. Biol. Chem., 1927, **76,** 729.
8. Ellis and Zeller, ibid., 1930, **89,** 185.
9. Callow and Kitchin, Food Invest. Board, 1931, Rept. No. 137.
10. Sinclair, Sci. Agric., 1926, **17,** 31.
11. Pomeroy, J. Agric. Sci., 1941, **31,** 50.
12. Johns, N.Z. J. Sci. Tech., 1941, **22,** 248.
13. Lush, Thomas, Culbertson, and Beard, Proc. Amer. Soc. Animal Prod., 1936, 29th meeting, p. 258.
14. Henriques and Hansen, Skand. Arch. Physiol., 1901, **11,** 151.
15. Dean and Hilditch, Biochem. J., 1933, **27,** 1950.
16. Callow, Food Invest. Board, 1935, Rept. No. 43.
17. ——, ibid., 1938, No. 45.
18. —— ibid., 1934, No. 143.
19. Lea, ibid., 1938, No. 60.
20. ——, ibid., No. 73.
21. ——, J. Soc. Chem. Ind., 1931, **50,** 343T.
22. Barnicoat, N.Z. J. Sci. Tech., 1930, **12,** 32.
23. Foot, Henry, Kon, and Mackintosh, J. Agric. Sci., 1939, **29,** 142.
24. Hostetler, Halverson, and Sherwood, North Carolina Agric. Expt. Sta., 1939, Tech. Bull., No. 61.
25. Hiner and Hankins, J. Agric. Res., 1941, **63,** 233.
26. Bolton and Baskett, Analyst, 1942, **67,** 254.
27. Romyn, Rhodesian Agric. J., 1937, **34,** 459.
28. Pedelty, Food Invest. Board, 1938, Rept., No. 64.
29. Hilditch, Lea, and Pedelty, Biochem. J., 1939, **33,** 493.
30. Hilditch and Shorland, ibid., 1937, **31,** 1499.
31. Hilditch, The Chemical Constitution of Natural Fats. Chapman and Hall, London, 1941.
32. Ellis and Isbell, J. Biol. Chem., 1926, **69,** 239.
33. Crawford, Pery, and Silva, Medical Res. Council, 1932, Spec. Rept. No. 175.
34. Gibbs and Agcaoili, Philippine. J. Sci., 1910, Section A, **5,** 33.
35. König and Schluckebier, Ztschr. Untersuch. Nahr. Genussmtl., 1908, **15,** 641.
36. Ellis and Isbell, J. Biol. Chem., 1926, **69,** 219.
37. McMeekan, J. Agric. Sci., 1940, **30,** 387, 511.
38. Channon, Jenkins, and Smith, Biochem. J., 1937, **31,** 41.
39. Eckstein, J. Biol. Chem., 1929, **81,** 613.
40. Banks and Hilditch, Biochem. J., 1932, **26,** 298.

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SOIL EROSION AND SOIL CONSERVATION IN THE COLONIAL EMPIRE

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With PLATES 6–9

Introduction.—In 1937 an article by Sir Frank Stockdale appeared in this journal in which the position in regard to soil erosion in the Colonial Empire was described and discussed. During the intervening period there has been a marked increase in awareness of the dangers involved and in many places considerable progress has occurred in the application of soil-conservation measures. Interest has been stimulated by the action of successive Secretaries of State for the Colonies who have repeatedly drawn the attention of Colonial Governments to the matter. In 1938 Mr. Ormsby Gore (now Lord Harlech) addressed a circular dispatch to Colonial Governors in which attention was invited to the question and the importance stressed of according to soil-conservation measures a prominent and permanent place in the policies of Colonial Governments. Particular emphasis was laid on the point that such measures should not be regarded as purely the concern of the specialist Departments of Government but as a matter of major policy having a direct bearing on the welfare of the communities.

To assist governments, the resources of which were insufficient to embark on conservation projects, the provision of grants from the Colonial Development and Welfare Fund was contemplated. Since then the matter has been kept under constant and continuous review. Notwithstanding the events of the war, interest has markedly increased, and although developments have been to some extent impeded by the necessity for deflecting man-power for military duties, causing the depletion of agricultural and forestry staffs and of available labour, nevertheless marked progress has been made.

Probably the most important advance is the growth in popular appreciation of the dangers inherent in erosion and the need for active steps to conserve the soil. This is not confined to the more highly developed sections of the communities, since in parts of Africa there is now considerable and increasing erosion-consciousness among native tribes. Coupled with this has been the growth of appreciation that conservation practices should not be regarded merely as remedial measures undertaken to counteract a specific danger, but that the need is for the evolution of systems of husbandry that will maintain and enhance the natural fertility of the land in which measures to ensure the conservation of the soil find their appropriate place. In large tracts of Africa, for example, there is increasing need for the development of intensive systems of farming to replace the methods of shifting cultivation and extensive ranching which have hitherto been widely prevalent and under the stress of increasing population pressure can no longer suffice to maintain, let alone to raise, the level of subsistence. Obviously no one system of husbandry can be laid down which is universally applicable; modifications will be needed

to meet the varying conditions of soil and climate and these must also be adapted to the needs and the ways of life of the cultivators and pastoralists themselves. In each locality therefore the primary necessity is to ascertain by experiment the system best adapted to the conditions and thereafter to secure its adoption by cultivators by precept, example, and if need be by a measure of compulsion.

A good deal of progress has been made in devising systems of mixed farming suited to varying conditions in which both crops and live stock play their part and by incorporating therein methods designed to counteract the dangers of erosion. It is of course uneven and the advances are not necessarily correlated with the gravity of the problem; for example, erosion is a grave menace both in East Africa and in parts of the West Indies, but for some time past the degree of awareness of the danger and progress with counteractive measures have been much greater in the former region than in the latter, although in the West Indies apprehension of the position has greatly increased of late years.

The general position in the dependencies was discussed in Sir Frank Stockdale's article referred to above; for convenience of reference it may here be said that the most widely prevalent form of erosion is sheet erosion, but in places extensive gullying also occurs, whilst in drier areas wind erosion is a serious menace. The chief contributory causes have been excessive deforestation, cultivation of lands which by reason of their steep slope should not have been opened for cultivation at all, unsuitable methods of cultivation, lack of provision for dealing with surplus run-off, the growth of crops conducive to erosion without adequate cultural safeguards, lack of protection from wind, and excessive concentrations of live stock, especially during dry periods, leading to overtrampling and consequent soil loss.

The most severe cases of damage from erosion have occurred in the East African Dependencies and in the High Commission Territories of South Africa. In West Africa the position is considered to be somewhat less serious, although in certain areas, notably in the Northern Territories of the Gold Coast, parts of the northern and eastern provinces of Nigeria, and parts of Sierra Leone, sheet erosion with some gullying is extensive. In the West Indies the position varies greatly, but erosion is very serious in some of the more mountainous regions of these island dependencies. Erosion is also an extremely serious matter in parts of Palestine and Cyprus.

The measures adopted to counteract erosion naturally vary to some extent according to conditions; they may be classified as follows: (*a*) agricultural, (*b*) forestry, and (*c*) engineering. Under (*a*) are comprised contour ploughing and planting, rotational strip-cropping, the use of grass strips and live wash-stops, the making of contour drains and wash-stops, the planting of wind-breaks to check wind erosion, restriction on the cultivation of those crops specially conducive to erosion, the use of cover crops and mulches, the control of grass- and bush-burning, and the improvement of pastures, combined with the introduction of rotational grazing and where necessary the reduction of stock. Under (*b*) are comprised the establishment of forest reserves and the closure to culti-

vation of threatened areas coupled with their reafforestation; such areas may include hill-tops, steeply sloping lands, gullies, and river catchment areas. An ancillary activity is the establishment of plantations of suitable trees for the provision of fuel and timber supplies for the use of populations. Under (*c*) are comprised the construction of contour bunds and terraces, the construction of stops and dams for the checking of gully erosion and the construction of works to deal with excessive run-off, as well as the maintenance of road-side drainage, neglect of which is often a source of gullying. With this is combined the provision of additional water-supplies for live stock and human consumption, thereby reducing excessive concentrations of live stock during dry seasons and its attendant overtrampling and erosion, and the reclamation of swampy areas by drainage, thereby increasing the land area available for cultivation in situations least liable to erosion.

In addition, the removal of part of the population in densely populated areas and their resettlement in other localities where land is more plentiful may be undertaken.

Experience tends to show that so far as is practicable it is good policy to reduce to a minimum any works for the direct control of erosion which have the character of major engineering operations, and to replace them wherever possible by operations carried out by the cultivators themselves, since it has been found that where such works are carried out by direct government agency in the first instance it is difficult to arouse the interest of native cultivators and to induce them to assume responsibility for their subsequent maintenance.

In the subsequent pages the position in the various dependencies is described. The various sections have been revised by the agricultural authorities of the territories concerned and the information presented summarizes the position at the present time.

East African Dependencies

Kenya.—The two main developments have been the institution of a special Soil Conservation Branch and the promulgation of the Land and Water Preservation Ordinance and Rules. The Soil Conservation Branch was instituted at the beginning of 1938 as a branch of the Department of Agriculture to perform advisory and experimental work and to supervise and carry out conservation schemes in European and native areas. The Land and Water Preservation Ordinance and Rules, promulgated in 1940, gave wide powers for the protection of the resources of the country. A Land and Water Conservation Committee was appointed in 1941 to advise the authorities empowered under the legislation to deal with the natural resources of the colony and protectorate. In addition the Control of Grass Fires Ordinance was enacted in 1941 with the object of lessening the effects of grass-burning on erosion. New and more comprehensive rules under the Land and Water Conservation Ordinance were promulgated in 1943.

Soil-conservation measures may be classified as follows: (1) the prevention of erosion on arable and grazing land at present in good

condition; (2) the reclamation of eroded areas; (3) the preservation of watercourses and water-supplies; and (4) afforestation.

The primary aim is to achieve conservation by means of a sound system of mixed farming in all areas suited to this type of agriculture.

It became evident by 1939 that the pace of erosion was accelerating; the outbreak of war resulted in further deterioration owing to the withdrawal of personnel for military service. Since then there has been a further realization of the dangers and progress has been made with conservation measures, but the urgent demand for the production of foodstuffs for war needs has resulted in further acceleration of erosion. In 1941 in the European-settled areas of Trans-Nzoia, Uasin Gishu, Nakuru, Koru, and Naivasha, 630 miles of broad-based and 750 miles of narrow-based terraces were constructed, and work was also undertaken in native reserves, District Agricultural Officers and trained instructors being provided for part- and full-time work. The total length of variable grade and level contour lines set out by the Soil Conservation Service during 1941 was estimated to be at least 2,200 miles. Shortage of staff, tractors, and oxen prevented full advantage being taken of the awakening of Europeans and natives to the evils of soil erosion. In the Central Province also considerable progress was made with the construction of narrow-based terraces, the planting of live wash-stops and of grass on eroding land, the closure of eroded hill-sides to grazing and cultivation, and the construction of dams. At the end of 1940 narrow-based terraces had been constructed on 70,000 acres and live wash-stops on over 17,000 acres in this province. Live wash-stops are only partially effective in that they do not dispose of excess run-off, and during the year narrow-based terraces were constructed on approximately 14,000 acres and over 200 grassed drainage-ways were established. Other measures included the establishment of grass paddocks, the closure of considerable areas of grass land to stock for part of the year; the protection of river and stream banks, and the planting of indigenous trees in the heads of valleys.

Terracing was begun in North Kavirondo, Nyanza Province, in 1941, following the establishment of live wash-stops and contour banks in 1940. In Central Kavirondo banks and trenches have been constructed to control erosion over 44,000 acres of cotton cultivation. The closing of certain grazing areas has not, however, proved successful as the resultant concentration of stock in adjacent areas has accelerated erosion. In the Coast Province the construction of narrow-based terraces on hill-sides has been undertaken. A demonstration area was closed to grazing in the over-grazed and badly eroded foot-hills around Msau, and the Local Native Council has agreed to the gazetting of certain areas as native forest reserves and to the reafforestation of areas unsuitable for cultivation or grazing. Surveys of agricultural and living conditions in native areas are being carried out to provide data for long-range planning.

Uganda.—In Uganda also considerable progress has been made. By 1939 it had become evident that a soil-conservation policy could not be confined to anti-erosion measures but involved a modification of the agricultural system of the country associated with general plans for rural

betterment. A Development and Welfare Committee was set up in 1940 under the Chairmanship of the Chief Secretary, the membership of which included the heads of the Agricultural, Educational, and Health Departments, with a Rural Development Sub-Committee comprising the heads of the Medical, Agricultural, Veterinary, Forestry, Geological, and Public Works Departments, the Heads of Provinces and three unofficials. This committee co-ordinates all programmes of rural development, so ensuring the full co-operation of all departments concerned.

The following broad lines of anti-erosion policy have been laid down:

(*a*) Prevention of the extension of semi-desert conditions in the north-eastern areas of the protectorate to the agricultural and pastoral areas in the south.

(*b*) The counteraction of the effects of overstocking in grazing areas by the organization of rotational grazing, the provision of additional water-supplies for stock, and the establishment of cattle markets for the sale of surplus stock.

(*c*) The development of a more rational land-utilization policy, aimed at removing from arable cultivation areas unsuited thereto, and planting to trees for the provision of village timber supplies.

(*d*) The evolution of a sound system of cropping which ensures the restoration and preservation of the crumb structure of the soil and the maintenance and enhancement of soil fertility.

(*e*) The institution of Crown and Native Administration Forest Reserves.

The carrying out of this programme has largely devolved on the provincial and district teams, which comprise representatives of those departments concerned with development.

(*a*) and (*b*). A policy for demarcating dry and wet season grazing-grounds in the semi-arid district of Karamoja in the Eastern Province has been drawn up, combined with early controlled burning, clearing to prevent the spread of tsetse fly southwards, and the reservation of areas as Crown Forests. In Teso in the Eastern Province the demarcation of pastures for a simple form of rotational grazing has been widely adopted with satisfactory results, and the local Native Administration Councils have co-operated very heartily in the measures. Throughout the Protectorate much attention has been paid to the provision of additional facilities for watering stock, with the object of lessening stock concentrations during dry weather. The construction of dams and impounding reservoirs is proceeding rapidly, particularly in Teso, Lango, and Karamoja districts. In Teso 10 dams had been completed at the end of 1942; in Lango 10 dams had either been built or were in course of construction. Eighteen impounding reservoirs were completed in Masaka, Ankole, and Karamoja districts by the Geological Survey Department. An extensive programme for the provision of bore-holes has been in operation for some time and has proved most successful in improving village water-supplies. The organization of stock markets, following successful disease-control, has succeeded not only in reducing the stock concentration in dangerous areas through the sale of surplus and 'scrub' animals, but has also achieved a definite and important change in the outlook of the African.

The stockowner to-day now appreciates the monetary value of his stock and is forsaking the old idea of *quantity* and looking more and more to *quality*.

The increased sale throughout the country is also reflected in the marked increase of meat consumption, with consequent benefit to the African dietary and nutrition. It is interesting to note that sales in organized markets alone rose from 42,431 cattle in 1938 to 130,048 in 1942. The estimated annual slaughtering in the Protectorate is in the region of 350,000 head of cattle and 630,000 goats.

(*c*) In 1941 the area of Crown Forests was increased by 380 sq. miles and Native Administration Forest Reserves by 14 sq. miles, permanent fuel reserves were increased by 600 acres and windbreaks established over 5½ miles in Kigezi, whilst large distributions of planting materials of eucalyptus and other timber and fuel trees were made. Early controlled burning was carried out over a total area of 1,500 sq. miles in the Eastern and Western Provinces.

(*d*) One of the first lines is the encouragement of a more rational use of live stock with stall feeding for manure-making purposes in thickly populated areas, and controlled grazing of resting strips and communal pastures elsewhere; it is recognized that the key to soil conservation in most areas is the maintenance of the crumb structure of the soil, and that this can be achieved by laying down arable lands to grass periodically and the development of strip-cropping. To elucidate the details, numerous experiments are in progress on the establishment and management of grass leys and on the incorporation of cattle in the system of land management. Remarkable success has attended these methods in various parts of the Protectorate; in Teso it is estimated that 90 per cent. of the land under annual crops is now strip-cropped with narrow grass strips interposed between the cultivated contour strips. In Mengo and other parts of Buganda in the vicinity of Lake Victoria the control of erosion is practised by the establishment of strip wash-lines planted in elephant grass (*Pennisetum purpureum*); over 8,000 plots were so planted in Mengo in 1941 and 6,000 plots in Masaka were bunded; in the badly gullied area around Kampala many hundreds of gullies have been stopped by the Native Administrations working in association with the instructors of the Department of Agriculture.

Some areas have been selected for intensive demonstrations in rural reconstruction. Steps have also been taken to ensure that soil-conservation measures are fully observed in Government-operated cultivation. Badly controlled drainage from roads is at times a cause of serious gully erosion, and special attention is paid to this question by the Public Works Department, whilst in the Eastern Province and in Buganda rules have been drawn up for the guidance of Native Administrations in making their own roads so as to minimize the risk of damage to adjoining lands.

Vigorous propaganda directed to spreading information concerning the dangers of erosion and the means of counteracting it is carried out through the medium of the vernacular press, and by lectures and talks. An inter-departmental conference on rural betterment was held in 1941 at which the position and progress in regard to anti-erosion measures

were exhaustively discussed. It can in fact be said that there has been a very general awakening of public opinion to the dangers of the position throughout Uganda, and that control measures are being very actively prosecuted, despite difficulties arising from the war.

Tanganyika.—This was one of the earliest territories in East Africa to realize the dangers of the erosion position, and for some time past Native Authority Rules have been in operation in the majority of districts to enforce soil-conservation measures and to control the damage done by indiscriminate burning of bush. In 1938 an instruction was issued to all heads of Government Departments concerned with land utilization, and to all District Officers, that the adoption of planned measures for the control of erosion was an integral part of the policy of the central Government.

Considerable progress has been made and certain of the Native Administrations have very actively collaborated in carrying out control measures. Limitation of staff and especially the drafts on man-power arising out of the war have handicapped efforts, and there is need for additional trained African personnel, who are essential for making and maintaining contact with the cultivators and their chiefs and leaders. Nevertheless the position cannot be regarded as unsatisfactory, having regard to the special difficulties.

The measures adopted include contour banking and ridging, the planting of contour hedges and windbreaks, the demarcation and protection of exposed hill-tops, steep slopes, river sources, and river banks, the control of grass-burning, the amelioration of soil conditions by manuring combined with the development of mixed farming, the demarcation and establishment of forest reserves, the introduction of simple deferred grazing schemes, and the reduction of the numbers of live stock by encouraging sale. The provision of water-supplies especially at the periphery of over-populated and over-stocked areas so as to allow more even distribution of population and live stock is an outstanding requirement.

In some areas the practice of organizing tribal 'turnouts' of labour for conservation measures has made considerable progress and is now a well-recognized procedure.

Latterly there has been increased collaboration between the Departments of Agriculture, Veterinary Services, and Forestry in conservation measures and the services of the botanist attached to the Veterinary Department have been available to advise on the work of the three departments throughout the territory. This has resulted in a number of comprehensive schemes being put forward jointly by the three departments. In certain districts teams of African agricultural instructors have been organized for continuous work on conservation, and as more staff becomes available operations on these lines are being extended.

Considerable areas have been protected in some degree by contour ridges, broad-base terracing, and the re-alinement of ridges and hedges. Thus on the slopes of Kilimanjaro upwards of 60,000 acres in arable cultivation have been demarcated and protected by contour banks; in Sukumaland and in the Central Province progress has also been made. In the Usambara mountains 50,000 acres of native land have now been

protected by live contour hedges. Many hundreds of small gullies have been planted up with elephant grass and sisal in Mwanza district. In Moshi terracing equipment acquired by the Department of Agriculture was employed in terracing operations on farms cultivated under maize.

An extensive programme of conservation works by tribal 'turnouts' has been laid down for the Central Province, including the badly eroded Kondoa area, Dodoma, and Singida. The schemes aim at the control of erosion on 5 million acres of pasture and 1 million acres of arable land within 10 years; some small progress has already been made there, but a real attack on the problem must wait until after the war.

In the Sukuma district of the Lake Province it is estimated that as much as 300,000 acres of grazing are now annually reserved during the rains for dry-season use, and an even greater acreage is under some measure of grazing control in the Central Province.

Some 1,200 hill-tops have been closed to cultivation at various points and approximately 215,000 acres declared as additional forest reserves. Concurrently there has been extensive distribution of the planting material for reafforestation, upwards of a quarter of a million young plants having been disposed of by the Forest Department in 1939–40. In Mwanza district alone, for instance, between 700 and 800 acres were planted with *Cassia siamea* in 1942 in communal village plots.

A considerable number of dams of varying size for the provision of water for stock have been constructed. In the last four years 14 dams have been dug in Shinyanga and 2 in Mwanza district.

There has been some improvement of farming standards in many parts of the territory, especially in the Lake Province where the use of cattle manure is extending. The campaign for the increased production of food crops has emphasized the need for better farming methods combined with soil-conservation measures.

Marked progress has been made with schemes for the marketing of stock surplus to the carrying capacity of the land through the extension of local cattle markets. The sale of cattle by native stock-owners has now reached the impressive number of 250,000 a year, which is more than double the pre-war figure; a large proportion of these animals is being purchased by Messrs. Liebig's for their meat-preserving plant in Kenya.

The eradication of tsetse fly is closely linked to soil conservation since in certain areas the relief of congestion of human and live-stock population is dependent on reclaiming adjacent fly-infested land. In reclaimed areas it is important that the land rendered available shall not be ruined subsequently by overstocking and defective husbandry. In the solution of this problem the Departments of Agriculture, Veterinary Services, and Tsetse Research are collaborating.

In other areas of the Territory where rainfall is higher but stock population less dense, the problems are less urgent, but nevertheless progress is appreciable although less spectacular. In the mountainous areas centred on Rungwe mountain and the Livingstone mountains natives are showing increasing interest in soil-conservation measures. The excellent indigenous system practised by the Wamatengo tribesmen of the Songea district is being fostered and extended where possible.

It can be said that whilst the need for much more extensive operations is urgent, nevertheless the problem is now well understood and, despite difficulties arising from the war, progress has continued.

Northern Rhodesia.—Northern Rhodesia is some 290,000 sq. miles in extent and has a population of about 15,000 Europeans and 1,400,000 natives. There are large tracts of low fertility, and tsetse fly is prevalent over wide areas. Widespread soil erosion is not likely to occur, but serious situations have arisen locally owing to excessive concentrations, relative to the carrying capacity of the land, of man and live stock. Most of these concentrations are, naturally, an indirect result of European occupation. Over the greater part of the territory the rains are confined to the months of November to April inclusive and vary from 20 in. in the extreme south to 60 in. in the extreme north-east. Active measures for the checking of erosion have so far been confined to the maize-belt of the Southern Province, the Abercorn and Isoka districts of the Northern Province, and to the Fort Jameson and Petauke districts of the Eastern Province. There are, however, other areas in which soil impoverishment and soil erosion will receive attention as soon as circumstances permit. In the three areas in which work is in progress conditions, and consequently the remedial measures adopted, differ widely.

The maize-belt of the Southern Province lies on the more fertile and accessible land bordering the only railway. It is occupied by European and native farmers and, being 'fly'-free, carries a large head of cattle. Several European farms have been contour ridged in recent years and interest in this form of protection is increasing. In the native area the opportunity for the sale of surplus maize and the introduction of the plough have led to the cultivation of greatly increased acreages and, with the abandonment of the traditional system of bush fallows, to soil impoverishment and erosion. Three agricultural stations serve this vitally important area which, from its soils and geographical position, affords an opportunity of developing farming as a business rather than as a mere means of subsistence. Field works consist of contour ridges and grass strips, and some 25,000 acres of garden had been protected by these means by the end of 1942. Soil impoverishment is being tackled by the introduction of a 4-course rotation in lieu of continuous maize cropping and by the use of manure and compost. This is a much slower process than soil protection by departmentally constructed field-works, and although it is realized that, ideally, the two remedial lines of action should be taken simultaneously, the need for protection *per se* is such that its pace must not be restricted. The adoption of improved farming methods is steadily spreading, and the present policy will at least ensure that there is land left on which to practise them.

The 'chitemene' system of finger-millet culture is traditional over the plateau of the Northern Province. It involves the annual lopping of trees over a large area to provide branches for burning on a relatively restricted patch in which millet is subsequently sown without cultivation. The system obviously demands a large area of woodland per family. In native reserves of Abercorn and Isoka districts the population was too large for safe adherence to the traditional method, and insufficient interval

between cutting cycles caused deforestation. In these districts 213 village areas have been demarcated within which annual loppings are now conducted on a 15–20-year rotation with fire-protection of the recovering woodland. At the same time the gradual development of subsidiary gardens cultivated by hoe is proceeding with a view to increasing still further the carrying capacity of the land. Such gardens are protected by contour banks.

In the Eastern Province most of the land was formerly owned by the North Charterland Exploration Co., and the large native populations of Fort Jameson and Petauke districts were confined to inadequate reserves. Devastation, unparalleled in Northern Rhodesia, resulted. The estate was, however, acquired by Government in 1941, and steps were taken immediately to dilute the population of the reserves by orderly settlement of the new land.

Following a soil and vegetation survey, areas estimated to be capable of supporting the population of each village were demarcated in advance of settlement, and cultivation blocks were laid out, separated by contour strips of vegetation in which cultivation is prohibited. By the end of 1942 new areas had been settled by 156 villages comprising 18,000 inhabitants. The work is proceeding and will take some years to complete. Meanwhile soil-conservation work has been started in the original reserves. The traditional system of mound cultivation is particularly conducive to heavy run-off and erosion. A change to ridge cultivation on the contour is being introduced with the additional protection of departmentally constructed storm drains at suitable intervals. There is also much need for improved agricultural methods, including the use of all available manure, but the most urgent matter is the rapid dilution of the population in order to give improved methods a chance.

Nyasaland.—Soil-conservation measures are the responsibility of the Agricultural Department working in close collaboration with the Forestry, Veterinary, and Administrative services. In 1937 an Assistant Conservator of Forests was seconded for duty as Soil Conservation Officer for a period of three years, and as a result of his investigations the Government in 1939 issued a circular directing attention to the dangers of soil erosion and laid down a policy for the conservation of the land. The measures recommended included controlled early burning as a first step in the control of bush fires; the preservation of natural vegetation on the banks of streams and steep hill-sides; cultivation on contour ridges instead of on mounds (with checks in the form of silt pits or low mounds constructed between the ridges); manuring and rotation of crops; prevention of run-off from higher areas by drains and by banks, or belts of vegetation across the top of the gardens; and the rotational grazing of pastures.

It was recognized that in six regions of the protectorate erosion had reached such an advanced state that immediate measures for control were needed. Assistance was sought from the Colonial Development Fund and in 1940 a free grant of £16,500 was sanctioned to defray the cost of anti-erosion measures.

Throughout the protectorate there has been a general change-over to ridge cultivation. The ridges are laid out on the contour, and on the steeper

slopes they are 'boxed' or tied by smaller ridges running at right angles to the contour ridges. The continuance of these measures, supplemented by the burying of waste vegetation, is generally advocated, but a permanent soil-conservation programme must have as its major objective a reorganization of the village lands and the introduction of strip-cropping with periodic laying down to pasture. Such a reconstruction of African village life presents many problems, and to study these problems an area was selected, and an 'Administrative Unit' was set up to carry out the initial survey. The first unit was formed in March 1941 to operate in a selected area in the Cholo district, with an officer of the administration in charge, assisted by representatives of the Agricultural, Forestry, Veterinary, and Medical Departments. The programme included the closing to cultivation of all steep slopes, the planting of lines of bamboos to demarcate these areas, the redistribution of land remaining open to cultivation, and its protection by ridge terracing and contour ridging. It is believed that the work of this unit will point the way to satisfactory methods of combating soil erosion throughout Nyasaland, and it is hoped to establish spaced administrative units in all districts. Uncontrolled immigration has resulted in over-population in Cholo, the density amounting in some places to as many as 600 or more per sq. mile. Schemes are under consideration for controlling immigration and for the resettlement of the population of the more congested areas.

A Soil Conservation Officer was appointed early in 1942 and an Assistant Soil Conservation Officer in December 1942, and these officers are now engaged on surveys of areas considered suitable for settlement to relieve the pressure on some of the overcrowded and badly eroded lands.

In North Nyasa the Misuku Land Conservation Scheme entered its fifth year in 1943 and cultivators are beginning to realize the benefits derived therefrom. It is hoped that in due course they may be trusted to maintain conservation measures with no more than ordinary supervision.

Forest reserves have a profound bearing on soil conservation and over 5,000 village forest reserves have been established under the control of the village headman. The Veterinary Department is carrying out a policy of gradual de-stocking of those areas where over-stocking is threatened.

It can be said that although progress has been to some extent retarded by the war, nevertheless marked advances have been made. There is general awareness of the dangers, and a noteworthy degree of collaboration between departments of Government and the Native Administration Authorities in conservation operations.

Somaliland Protectorate.—The greater part of the country is semi-arid and the beneficial effect of the scanty rainfall is much reduced by desiccating winds. Agriculture is carried on at between 4,000 and 5,000 ft., but at least 90 per cent. of the people are pastoralists and graze their flocks and herds on the vast plains. Owing to the scarcity of water the human and stock populations are tied to the wells, except for comparatively brief periods after the two rainy seasons when they migrate to outlying grazing areas.

Such a state of affairs leads to excessive pressure on the vegetation in the vicinity of the wells, and this is frequently shown by complete

denudation of the ground-surface and the resultant removal of surface soil by wind and water. In the open woodland country, overgrazing and tree-cutting combined are giving rise to windswept sandy wastes, and it has been estimated that 10 per cent. of the country is devoid of all vegetation.

Even in the plateau area soil erosion is far advanced, and much of the rainfall runs off the hard surface and is lost. It has, however, been proved that most of this area is not beyond man's power of saving, and before the war the value of deferred grazing was abundantly proved and the protection of catchment areas and watersheds recognized as a first essential in any programme of improvement.

In the cultivated areas the Somali was, before the outbreak of war, beginning to recognize the benefits of terracing, contour grass-strips, and contour cultivation. Under the stress of war deterioration set in, but in 1942 a survey of the grazing areas was made and recommendations designed to ameliorate the conditions are under consideration. It is hoped that in this connexion a general protectorate grazing-plan may be formulated and accepted.

Zanzibar.—Soil erosion is not an acute problem in the Zanzibar Protectorate, as the live-stock population is comparatively small and there are no undue stock concentrations; the principal crops are tree crops, the planting of which is in itself an anti-erosion measure when properly carried out. Much of the highest land is planted with cloves, and a considerable part of the remaining land is under coco-nuts. In areas where cloves have died out through one cause or another there are indications that soil erosion might become a serious problem if cloves and coco-nuts were replaced by annual crops, unless protective measures were undertaken.

At places a little gully erosion has taken place, notably on Masingini Ridge. The remedial measures first undertaken consisted of the planting of lines of banana and Tephrosia, but this was not completely successful and in 1940 the construction of contour terraces and the planting of trees and grass on the higher slopes of the catchment areas was begun with more satisfactory results.

In all areas where erosion is likely to occur the advisability of restricting the cultivation to the lower slopes and of strip-cropping is being impressed upon plantation owners.

Under the pressure of shortage of imported foods large areas are being put under food crops by unskilled cultivators, and although ridging along contours is enforced wherever possible, there are considerable areas where lack of ridging and absence of strips occur. There is also too great a proportion of cultivated to fallow land, which is inevitable under present circumstances.

South Africa—High Commission Territories

Basutoland.—Soil erosion has long been observed in the lowlands of Basutoland and by the middle of the last decade it had assumed very threatening proportions. The Commission appointed by the Secretary of State for Dominion Affairs to inquire into the financial and economic

position of Basutoland called attention to the matter in its report (published in 1935) and expressed the view that the amelioration of conditions in this regard was a matter of urgency if the economic future of the country was to be safeguarded. It recommended the preparation of a scheme to be financed from Imperial funds for dealing adequately with the matter.

The main cause of sheet and subsequent gully erosion is the uncontrolled run-off of storm-water from the overgrazed lower slopes of the mountains and the hills in the lowland areas of the territory. Sheet erosion is evident in all cultivated areas, particularly in the lowlands, and gully erosion has destroyed most of the lowland valley bottoms. It is clearly shown by the complete ecological survey carried out in detail all over the country and from subsequent investigations by experienced Forest Officers that the ecology of the country proves that Basutoland has never carried a forest cover. This, coupled with excessive overgrazing of Basutoland's fine pastures, permits of heavy run-off, which has removed millions of tons of soil from the territory. As a result of the Commission's report a sum of £160,000 was made available, under the Colonial Development Act, to carry out soil-conservation measures, which included the planting of trees.

It was realized that a campaign of this nature must involve considerable interference with established agricultural practices and some disturbance of the normal way of life. Accordingly immediate steps were taken to educate native opinion to appreciate the need for protective measures and to accept the methods proposed. This was done by means of propaganda, explanation, and demonstration. A strong lead was given in the matter by the then Paramount Chief, who readily co-operated and asked that anti-erosion measures should be inaugurated on his own land.

Demonstrations of the methods of soil conservation were started in 1935 and large-scale operations in 1936. The measures adopted comprised the laying out of contoured, broad-based terraces and the introduction of ploughing along the contour, the construction of earth-dams to check gully erosion and provide additional water-supplies for stock, combined with the planting of grass and trees to stabilize contour banks and to assist the silting up of gullies, and the fencing of the banks of dams and of plantations to prevent damage by live stock. To carry out the work a soil-conservation section of the Department of Agriculture, consisting of seven qualified agricultural officers and a civil engineer, was constituted under the charge of the Director of Agriculture. It was provided with the necessary survey instruments, terracing equipment including tractors and graders, &c.

Combined with these measures there must be improved methods of agriculture based on the introduction of mixed farming in place of the existing system. It is considered that the maintenance of crumb structure in the soil should be the aim and that this can only be maintained by suitable agricultural methods. To assist in popularizing improved systems of agriculture three mixed-farming demonstration units have been inaugurated.

As the capacity of soils for absorbing and holding water is a first necessity

in the prevention, particularly, of sheet erosion, and as the lowland soils in the territory had been depleted of humus or organic matter, it was essential to make available as soon as possible all the kraal manure for this purpose in the territory. All manure had been used as fuel for domestic purposes, and to overcome this abuse the extensive planting of trees was necessary. Furthermore, apart from reserves of fuel, protective forest belts were necessary in badly eroded catchments and on badly eroded hill-sides. Therefore the planting of trees was prosecuted from the inception of the scheme. Recently on the suggestion of the High Commissioner an all-out tree-planting campaign was instituted, and it is hoped to secure the planting and establishment of some 2,000,000 trees per annum for the next 10 years, with the dual object of providing protection to the land and also rendering available supplies of firewood, thereby reducing the use of cattle manure as fuel.

By the end of 1942 nearly 100,000 acres of eroded land had been efficiently dealt with by the soil-conservation organization in the lowlands with strikingly beneficial results, and some 9,000 acres had been dealt with by the use of grass strips in the mountain areas where the soil is far more fertile and incipient gullying is not so prevalent. It is evident that the use of these grass strips on the richer soils where incipient gullying is largely absent provides a cheap and relatively efficient means of checking sheet erosion. But in the light, sandy soils of the lowlands where gullying occurs to an excessive degree, contour terrace-banks, whether light or heavy depending upon conditions, must continue as the chief means of stabilizing the soil. By the end of 1942 122 dams had been constructed and the water-supplies thus made available have naturally assisted in preventing the destruction of pasture by tramping out.

The considerable measure of success which has already attended these operations has only been possible through the support of the Paramount Chief and the tribal authorities which, as a result of a policy of effective propaganda and explanation, is fully forthcoming. The policy has been given a legal basis by the issuing of a series of 12 orders under the Native Administrative Proclamation setting out the cardinal points which must be observed in conservation operations in tribal areas. (Plate 6.)

Bechuanaland.—Sheet erosion and desiccation are widespread in many parts of the eastern portion of the Bechuanaland Protectorate below the Kalahari escarpment and, particularly, in the river valleys which flow east from the escarpment. A certain amount of gully erosion also occurs. Erosion is caused in Bechuanaland by over-concentration of live stock in the vicinity of the limited number of water-supplies available; hence the destruction that has taken place in the river valleys. Cultivated fields, particularly those lying in the river valleys, like the general pasture land in the valleys, have also suffered from sheet erosion. The overgrazing in the valleys has endangered the life of the pasture on which the economic life of the inhabitants depends. The tramping out by stock has in places been so severe that tracts of country have been denuded of vegetation.

The provision of additional water-supplies to permit of the removal of live stock from the valleys is the principal measure which will check the

present erosion. Therefore the provision of additional water-supplies is regarded as the principal project in Bechuanaland, and to this end a grant of £139,000 was secured from the Colonial Development Fund to cover a five-year water-development plan, commencing in May 1936. The first object was to supply domestic water-supplies in tribal reserves and to develop water-supplies in grazing areas, many of which had hitherto been useless owing to lack of water. As the work has proceeded, there has been a progressive dispersion of stock from overcrowded areas with the consequent reduction of tramping out and the evils attendant upon it. By the end of 1940 a total of 142 water-supplies had been provided. The continued provision of water-supplies to maintain the live stock and combat soil erosion practically ceased at the outbreak of war, and only very minor work of this kind has been carried out since that date. The provision of additional waters may be termed the provision of life-blood to this territory, and the continued destruction of pasture will carry on until this work can be resumed when boring apparatus, &c., once again becomes available.

A further measure introduced to preserve the territory was the prevention of veldt fires, and the position in this connexion improved rapidly as a result of the development of greater tribal control. Controlled burning is at times necessary to prevent devastating fires due to accumulated dry herbage, and the great object was to prevent fires occurring in the areas where water had been provided, water that made available reserved grazing. Unfortunately in 1941 fires were widespread, owing to the population being preoccupied with recruitment for the African Auxiliary Pioneer Corps at a time of the year when winds were high and the pasture dry. But there is little doubt that, with the provision of further water supplies and the gradual betterment of pasture- and fire-control measures, the destruction by fire will decrease.

The Forest Department, which came into being at the end of 1939, is making a study of trees suitable for providing protection against soil erosion and for the supply of building and fuel timber for the people. Generally speaking, the territory, unlike Basutoland, is well provided with timber, except in close proximity to the big native towns or villages, such as Serowe with 30,000 inhabitants, where the trees have been cut down for building purposes and firewood. The Forestry Section will endeavour to deal with this aspect when, from experimental plantings, sufficient data are available to know which types of trees will exist under the semi-arid conditions obtaining in the protectorate.

Swaziland.—As in the other High Commission Territories, soil erosion occurs in Swaziland largely as the result of overstocking in certain of the Native Reserves, the concentration of too great a number of cattle at certain dipping tanks, and unsatisfactory cultural practice. Sheet erosion is fairly widespread and gully erosion occurs in a few places.

The most important anti-erosion measures so far undertaken have been:

(*a*) The construction of an additional 50 dipping tanks, made possible by a grant of £5,000 from the Colonial Development Fund.

(*b*) The construction of dams for the provision of additional water-

supplies for live stock. This work, which began in 1938, was made possible by a grant of £16,000 from the Colonial Development Fund: £2,000 of this sum was available for anti-erosion measures in cultivated fields and to check gully erosion. By the end of 1940 a total of 17 dams had been constructed, and in 1941 the dam-construction programme was placed on a more satisfactory basis, since when this work has proceeded steadily, augmented by a further grant which will permit of the provision of a minimum of 60 water-supplies.

(*c*) At the Aird Government Farm good results have been obtained from planting Napier grass in strips on the contour. Not only do these strips act as a safeguard against erosion by stabilizing the soil, but they supply a large quantity of fodder for stock. As a result of these experiments and after much propaganda, this work has now been extended on a fairly large scale in certain of the Native areas and has found favour for use on European-owned lands. In one Native area nearly 10,000 acres have been permanently safeguarded by the use of strips of Napier fodder grass, and individual natives are using this system in various parts of the territory. Progress continues, but can be much accelerated when additional staff becomes available.

Where serious gullying has occurred the worst instances have been dealt with by establishing contour banks and drains. (Plate 7.)

West Africa

Gambia.—Soil erosion is not a serious problem, though some movement of the sandy soil takes place after heavy rainstorms. A series of orders made by Native Authorities in the protectorate prohibit the burning of growing grass, and bush land to be used for farming purposes must be burned early. A Forest Commission submitted a report in 1940 dealing with the protection of existing forest and the reafforestation or cultivation of economic trees on denuded areas, but no comprehensive soil-conservation policy has yet been formulated.

Early burning is advocated in order that regrowth may afford a measure of protection before heavy rains fall, and this is meeting with success. Both the flat and the ridge-and-furrow systems of cultivation are practised in the Gambia; in the latter, the desirability of making the ridges across the slope is impressed upon the people. Emphasis is also laid on the value of cattle manure and compost, thus leading to more intensive farming and aiding soil conservation.

A scheme to extend greatly the cultivation of rice on the tidal flats will shortly be put into execution. This, if successful, will transfer a certain amount of cultivation from the less fertile dry lands, but there is no problem of land hunger in the Gambia, or of serious erosion of uplands as in Sierra Leone. The dearth of timber has been aggravated by war-time needs, and the establishment of a Forestry Department as a part of the work of rehabilitation is now under consideration.

Gold Coast.—Primitive farming methods are leading to soil degradation in the Northern Territories. Recent changes in the economic and social life of the people aggravate the damage resulting from shifting cultivation, uncontrolled grazing, and annual grass fires. In the coastal

areas, where the population is dense and large tracts of forest have been cleared, erosion is also evident.

No separate organization has yet been set up to deal with soil-conservation problems. The subject is dealt with by the Departments of Agriculture and Forestry, and, although the operations are still largely in the experimental stage, a number of measures have been inaugurated. The area of Forest Reserves established up to March 31, 1943, totalled 6,940 sq. miles, but with the exception of 1,088 sq. miles the reserves lie in the forest zone, where erosion is not a major problem. In Ashanti the Native Authorities issued orders in 1938 forbidding the cutting down of forest for planting new cacao farms. In the northern savannas rules were made in 1938 to control grass-burning.

In the northern territories, particularly in Zuarungu and Bawku, sheet and gully erosion occur; the prevention of grass fires and the increased use of farmyard manure constitute the most effective conservation measures. Planned migration from over-populated areas is also under consideration. Mixed farming as a substitute for shifting cultivation has been experimented with and developed since 1937. The planting of shade trees and windbreaks in the cacao-belt is another accepted line of attack.

The active co-operation of certain Native Authorities in conservation measures has been secured, as instanced by the orders mentioned above. From 1938 to 1942 1,130,000 trees were issued to farmers for planting, and the greater proportion of them were planted as shade trees for cocoa, a few shelter-belts also being established.

No large-scale measures can be expected until after the war, but in the meantime useful data are being collected which should enable a larger programme to be adopted as soon as supervisory staff is available. (Plate 8.)

Nigeria.—Soil degradation and erosion are taking place over much of the savanna country in Northern Nigeria and also in the more densely populated areas of Southern Nigeria.

Insufficient staff has prevented the establishment of an organization designed specifically to deal with soil conservation, but a considerable amount of work has been done by the Department of Agriculture in improving agricultural methods, and by the Forestry Department in the establishment and protection from burning of forest reserves. The Public Works Department are also co-operating by controlling excessive run-off from the roads and by abolishing the clean weeding of road edges. Provincial Welfare and Development Boards are taking an interest in soil-conservation measures.

A promising and constructive line of approach is the extension of the cultivation of rice, wheat, onions, sugar-cane, and other suitable crops in the swamps and marshy valleys, with the object of relieving the pressure on the over-farmed uplands.

The clearing and farming of steeply sloping land have in places been prohibited, the areas thus released being used for fuel and timber reserves. Communal forest areas have been established to prevent the indiscriminate cutting of timber and scrub for firewood.

In Southern Zaria work has been started to test the possibility of farming the rich soil of the thickly wooded and steep-sided valleys

without either laying the seeds of serious erosion or increasing the incidence of sleeping sickness among the population.

Other measures include contour ridging, broad-base terracing, the planting of natural fallow grasses such as *Andropogon gayanus*, and the planting and preservation of economic trees. Propaganda to enforce the Burning of Bush Order is also being intensified.

In the more northerly districts of low rainfall, where wind erosion is of pressing importance, measures include the planting of shelter-belts, the establishment of line-fences, and grass strips or bunds between the fields.

A start has been made with the rehabilitation of 'bad lands'; measures include the digging of shallow contour trenches, and the planting of hardy indigenous species of grasses and other plants, those which first appear in ecological succession on this type of impoverished soil being selected.

It will be seen that anti-erosion work is still largely in the experimental stage, but valuable knowledge and experience are being accumulated which can be applied after the war when staff conditions admit.

Sierra Leone.—A pernicious system of shifting cultivation has degraded the soil in the upland regions of the western and southern parts of the territory. Degradation is progressing rapidly and erosion is now severe on the hills and slopes, the position in the Colony hills being particularly bad. The demand for farming land is insistent and nearly all of the original forest has been destroyed. The first requirement therefore is to exclude shifting cultivation on hill-slopes, and in consequence the policy has been adopted of endeavouring to relieve pressure on the uplands by encouraging the cultivation of river flats and valley bottoms, which by lowering the demand for upland farms will facilitate the declaration of forest reserves on the hills and slopes and the replanting of denuded areas with suitable forest trees.

To implement this policy extensive surveys of tidal and swamp lands have been carried out by the Department of Agriculture. An experimental station for work on rice cultivation was opened at Sembehem towards the end of 1938. Farmers were granted loans to assist them in felling the mangrove. The scheme, though on a small scale, was highly successful. In the first 2 years over 1,000 acres of virgin land were taken up. In the next year more than 1,000 additional acres were cleared, and with increased provision of funds to assist planting, rapid development can be expected.

To assist developments an Irrigation and Drainage Engineer was appointed in 1940, the cost being met from a grant under the Colonial Development and Welfare Act. A preliminary survey by this officer showed that upwards of 500,000 acres existed in the tidal coastal area which could be reclaimed for cultivation, and it is believed that a similar area exists as inland swamps. The Irrigation and Drainage Branch was expanded in 1942 and a scheme approved for the reclamation of 50,000 to 60,000 acres of swampy land during the next 5 years at a cost of £303,000 (including free plant), funds being provided by a combined grant and loan under the Colonial Development and Welfare Act.

Further proposals are under consideration for establishing water-

control over some 300,000 acres in the Southern Province (Bum-Kittam area) of potential rice lands; concurrently, proposals have been made for reafforestation in badly denuded upland areas. Forest legislation was enacted in 1942, and the collaboration of the Native Authorities has been secured in a plan for demarcating declared areas as forest reserves. A framework of shelter-belts and forest reserves was laid down in 1940; nurseries of forest trees have been established by the Native Authorities under the guidance of the Forest Department, and by 1941–2 7,500 acres of protective forest had been demarcated.

It can be said that the seriousness of the problem is now fully realized, and measures to counteract the evil are being energetically pursued.

St. Helena.—St. Helena is a small island with a total area of 47 sq. miles. The coastline consists of high perpendicular cliffs, above which the ground rises in fairly steep slopes to ridges in the middle of the island that are broken by narrow valleys and fissures descending to the sea. The rainfall is moderate, but varies considerably in different localities. At one time it is reputed to have been covered with forest, but most of this has been removed.

Erosion is a serious problem, due mainly to the effects of the strong trade winds following indiscriminate deforestation, uncontrolled pasturing of goats, donkeys, and sheep, and bad cultivation practices on exposed areas.

The island was visited in 1939 by Sir Frank Stockdale, who directed attention to the position and made recommendations for dealing with the question as a part of a policy of general agricultural rehabilitation. Funds for the execution of this programme were provided through a grant from the Colonial Development and Welfare Fund, and a start was made at the end of that year, an agricultural officer being specially appointed for the purpose. Since then there has been appreciable progress. The measures have aimed at the regulation of grazing, the protection of pasture lands by fencing, the reduction of the number of uncontrolled goats, reconditioning and reafforestation of denuded areas, the improvement of cultivation methods by the use of manure, and the establishment of terraced and contoured cultivation.

Legislation has been enacted 'to make provision for the preservation and protection of the soil and for the control and improvement of crop production and live stock'. With the powers provided goat-ranges have been defined and the numbers of goats on the island have been considerably reduced. Much effort has been expended on propaganda to make the inhabitants aware of the seriousness of the position, and with encouraging success. Stall-feeding of cattle, donkeys, and goats is extending. Already there has been a marked improvement in the herbage in areas where grazing is prohibited, and cultivators are beginning to adopt improved methods of cultivation. A start has been made with the planting of trees in protected areas, and it is intended to give increased attention to the provision of forest protection so soon as circumstances permit. Although the position remains grave, there has been already an appreciable improvement, and given continuity of the existing policy the outlook is not unhopeful.

Eastern Dependencies

Ceylon.—The serious nature of the soil-erosion problem in Ceylon has been recognized for some years. This is particularly true of tea and rubber estates, which occupy the hilly land in the regions of high rainfall. The introduction of ground-covers on rubber estates dates back to the 'twenties', but on tea estates the immediate practical disadvantages and objections to anything but the old practice of clean-weeding were more obvious and weighty, and it is but recently that the maintenance of a cover of selected soft weeds has become at all general.

Although a ground-cover is regarded as the most satisfactory first line of defence in preventing erosion, in that it anchors the soil and increases its absorptive capacity, the importance of other soil-conservation measures is not overlooked. Large estates have, from the earliest times, provided drains across hill-sides, but these were formerly dug at a relatively steep gradient. In more recent years the practice has been to construct the drains on the contour or at a slight slope and to provide catchment pits at intervals, so that any surplus water is led from the land in a silt-free condition. Stone terraces constructed on the contour are also extensively used where stone is available and, where the land is not too steep, earth excavated from drains is consolidated into 'bunds'.

The research institutes for the three major economic crops, tea, rubber, and coco-nuts have taken the lead in encouraging soil-conservation measures by investigations and demonstrations. The Department of Agriculture fills a similar role for the village agriculturist and is responsible for carrying out the policy laid down by the Ministry of Agriculture and Lands.

In 1937 an officer of that department was appointed in a part-time capacity as Soil Conservation Officer to make a special study of the subject. Early in 1939, however, he was seconded for other duties, and unfortunately the emergency conditions arising from the war situation prevented the resumption of his soil-conservation work. He was able, however, to submit a report containing definite recommendations for the better conservation of water and soil in Ceylon, which are likely to form the basis for legislation. In 1939 the Central Board of Agriculture accepted the report of a special Soil Conservation Committee whose basic recommendation was the constitution of a statutory body to be termed the Soil Conservation Board. The Central Board also recommended the early framing of a comprehensive Soil Conservation Ordinance, but this has had to be held in abeyance during the war.

The only form of compulsion which has so far been exercised is in respect of land opened under the Rubber (New Planting) Ordinance of 1938. All persons exercising rights under this ordinance are obliged to adopt certain minimum prescribed measures for the prevention of erosion. Advice and financial assistance are given to small-holders in the execution of the necessary work.

Ceylon is fully alive to the importance of conserving her soil. Considerable progress has been made in the adoption of protective measures, whose value is based mainly on empirical observations. Had it not been

for the war a more detailed study would have been possible and legislative action taken.

Hong Kong.—Both Hong Kong island and the New Territories offer a picture of bare hill-sides which have been heavily eroded in past years. Cultivation is almost entirely confined to the valley bottoms and the lower slopes of the hills in the New Territories. An extensive programme of reafforestation on hill-sides had been embarked upon by the Hong Kong Government with a view to providing the protection so badly needed and rehabilitating the denuded soils, as well as for providing some supplies of fuel and timber. The work had been in progress for a number of years prior to the Japanese occupation and had already shown some substantial results; it was being steadily extended. When peace returns no doubt it will be resumed.

Malaya.—The position presents some similarities to that in Ceylon although there are some differences. Until recently agricultural development was confined to the lower lands and little attempt had been made to open up the mountainous region of the centre of the peninsula. Shifting cultivation has never been a serious problem. Development was mainly in rubber, and in the earlier days clean-weeding without any safeguards against erosion was the usual practice. Extensive erosion had appeared early in the second decade of the twentieth century; this was followed by remedial efforts by the planting body, which first took the form of contour bunding and silt pitting, and was later followed by the planting of cover crops and the establishment of natural covers with selective weeding. A further source of difficulty was insufficiently controlled mining for tin, which led to extensive erosion with much gullying in places, coupled with silting rivers and consequent flooding and damage to cultivated areas through the deposition of silt. This condition was remedied by the application of much more strict control of mining operations.

The opening up of the mountainous area and the establishment of tea plantations after 1930 gave rise to a fresh series of problems, but these have been dealt with in the light of experience in Ceylon and other countries, and by 1941 the situation was well in hand.

Much work was done by the Rubber Research Institute of Malaya with a view to ascertaining the most suitable methods of erosion control in rubber plantations, the results of which were extensively applied. On small holdings the position has never been serious, since peasant cultivators of permanent crops such as rubber and coco-nuts have never practised clean-weeding in the manner formerly current on estates; this has served to check any tendency to erosion, and the only annual crop extensively planted is swamp rice, which does not conduce to erosion.

Towards the end of the period 1920–30 a serious situation was beginning to arise on lands cultivated in pine-apples in the southern and central part of the peninsula. At the time of the Japanese occupation this was being closely studied by the Department of Agriculture on the pine-apple experiment station in Johore, with a view to working out economic methods of obviating the danger.

Erosion is also a serious matter on the mountain slopes of the densely populated island of Penang.

Until 1939 no special organization existed for dealing with soil conservation, but in that year a standing central committee was appointed by the High Commissioner to investigate and advise on the problem, with sub-committees to advise on the technical, administrative, and legal aspects of the question. Evidence collected by this body showed that the position had considerably improved of recent years; a certain amount of damage was still occurring where bananas had been planted on unsuitable sites whilst the position on pine-apple plantations and on Penang Hill was serious.

Mauritius.—Soil erosion is not a serious problem; over 90 per cent. of the cultivated land is in normal times cultivated in sugar-cane, a crop which affords excellent protection against losses by erosion, whilst the system of cultivation employed, which includes long ratooning and the careful preservation of sugar-cane straw on the land, further assists in the process. The forests of the island are also well protected, and the Forest Organization is among the oldest in the Colonial Empire. There are considerable Government-owned forest reserves, and control is exercised over privately-owned forests. River reserves are maintained by statute for a prescribed distance from the water's edge on all major watercourses. As a result, notwithstanding the mountainous nature of the country and the erodible character of the soil, a high standard of protection against erosion has been achieved.

As a result of the war it has been necessary to plant a much larger area than usual in food crops, with corresponding reduction in the area under sugar-cane. It remains to be seen whether this will have any effect on the erosion position.

Seychelles.—This group of small islands is predominantly mountainous. In some of them and particularly in Mahé, the principal island, a narrow coastal belt of more or less level land surrounds the granitic mountain massif and from this the land slopes steeply up the mountain side. Cultivation extends far up these slopes in many places, and there has been considerable removal of the forest cover. The annual rainfall averages 90–100 in. and its distribution is somewhat erratic. Under these conditions severe erosion has occurred on the exposed slopes.

A free grant was made from the Colonial Development Fund for the 3-year period 1935–7 to further the work of reafforestation of degenerated areas, and some 450 acres were replanted. Schemes for terracing, irrigating, and generally reclaiming these badly eroded and worked-out slopes are now under consideration; and financial assistance to carry them out is being sought under the Colonial Development and Welfare Act.

Aden.—In southern Arabia the rainfall is in general too low for an efficient natural vegetation to cover the slopes and act as a check on run-off. Only by the efficient use of all sources of water, particularly flood water, can cultivation continue. In these circumstances an effective system of soil and water conservation forms an integral part of traditional cultivation, and although there is a constant movement of the soil from the slopes to the flats, efficient run-off control results in comparatively little silt-laden water reaching the sea. Soil erosion occurs where

flood waters are not controlled, and in some areas overstocking has led to soil degradation.

Wind erosion is a factor of importance in the alluvial areas, such as on the coastal plain, where it affects areas which have been withheld from cultivation for long periods. In such situations desiccation of the soil is followed by wind erosion. The remedy is, of course, to irrigate such soils and bring them back into cultivation.

The agricultural staff available is at present very limited, but some measures to improve the position have been possible.

The general view is that efforts to effect soil conservation should be directed to the maintenance and extension of the present system of flood control. The districts of Abyan, Beihan, and Ahwar, which depend largely on a system of flood-water irrigation, have been selected as areas for improvement. In past years flood waters have gone to waste owing to local insecurity and impoverishment, which resulted in the neglect of the deflectors and canals required for flood control. During the past two seasons active measures have been taken to remedy this state of affairs following an improvement in political conditions, and by a system of advances to cultivators willing to undertake the restoration of their irrigation systems. Such flood-water control works must naturally go hand in hand with increased production measures.

On the Audhali plateau a system of advances for farmers willing to improve or sink wells or recondition terraces has proved successful, and particular interest has been stimulated in areas where political difficulties have in the past caused neglect of such opportunities for the improvement of the natural resources. (Plate 8.)

Mediterranean Dependencies

Cyprus.—The need for soil conservation has been recognized in Cyprus since ancient times, and the art of terrace-making has been handed down by cultivators from generation to generation. Considerable areas are, nevertheless, in an advanced state of erosion, brought about by extensive and continued removal of forest growth and excessive and unrestricted grazing. The necessity of conserving the forests has been recognized since the British occupation in 1878, and legislation has been enacted from time to time to control grazing by sheep and goats. In approaching the problem the Department of Agriculture has aimed at devising control measures consonant with established agricultural practices. Attention has been given to the contour planting of annual crops, vines, and trees on erodible land; the encouragement of tree-planting on land which is too poor or too steep for field crops, and the protection of field boundaries and drainage beds. This has been combined with propaganda directed to make the farming community erosion-conscious and the establishment of demonstration areas and gully reclamations and forest-tree planting on steep hill slopes. By the end of 1941 a total of 18 soil-conservation demonstrations had been established. As a result soil-conservation measures are now being undertaken to an increasing extent by farmers on their own properties, and many applications have been received for Government assistance to this end. In 1942 a grant of £5,000 was made from Colonial

Development and Welfare Funds to assist the carrying out of soil-conservation measures in agreed areas. Much of the land under the control of the Forestry Department lies in the mountains, the slopes of which are steep and at times precipitous and subject to heavy rains; where forest protection has maintained a reasonable cover a precarious balance exists, but in many places forest fires, heavy grazing, and fuel-cutting have upset the balance, and progressive erosion has occurred. Soil-conservation measures have been kept prominently in view in recent reafforestation operations. In 1941 a grant of £210,000 was made from Colonial Development and Welfare Funds to provide for reafforestation, and this has enabled the Forest Department to undertake a large programme of reafforestation, which includes special protective measures to ensure soil conservation. The latter include the planting of protective strips combined with the construction of contour trenches or contoured stone bunds in forest areas where erosion is specially liable to occur.

Simultaneously steps have been taken to curtail or eliminate the grazing of goats and other live stock in forest areas. By the end of 1942 all lawful grazing had been eliminated from the most important forest areas of the southern range of mountains. This release of certain forest areas from excessive grazing produced an immediate and most remarkable improvement in the natural vegetation and natural regeneration of tree species. It is now obvious to all that the total clearance of grazing from forest areas is a necessary preliminary to allow the restocking of the forests to proceed economically. Forest grazing is still only under control in limited areas and there is much to be achieved before this question is satisfactorily settled. By the end of 1942 grazing had been eliminated from practically the whole of the mountain forest areas with an accompanying remarkable improvement in the natural vegetation. As a part of this policy there has been a considerable strengthening of the forest staff.

These moves have been accompanied by a considerable quickening of public interest in forestry questions. A Cyprus Forestry Association has been formed which has organized an Arbor Day and Tree-planting Week on an island-wide scale, and has imparted a considerable impetus to tree-planting on privately owned lands.

Reafforestation received some set-back owing to the heavy demands for timber for military purposes in the mid-eastern area, and also owing to the extremely heavy demands for wood fuel to tide over the war period of very limited importations of mineral fuel. It is hoped that the permanent effects of this policy will not be excessive, though it has resulted in much overcutting for the time being.

It cannot yet be said that public interest in Cyprus has been aroused over the subject of soil conservation, but certain branches of Government are now well aware of this evil, though it yet remains to draw up and apply long-term plans of action that would arrest and correct soil erosion. The visit of Dr. W. C. Lowdermilk, Chief of the Soil Conservation Service of the U.S.A., in 1939 did much to initiate thought on soil-conservation problems in Cyprus. (Plate 8.)

Malta.—Although the island contains a high percentage of rocky,

uncultivable waste land, the problem of soil erosion can hardly be said to exist to-day in Malta. Considerable tracts of fertile soil are to be found in the valleys, and, behind the numerous stone walls, which have been erected to free the land of rock, to prevent soil erosion, and to provide shelter for the crops from strong winds, there have been created—often by the transport of soil—small enclosed and terraced fields which are intensively cultivated. Soil is very precious in Malta and is efficiently husbanded.

Palestine.—Palestine is a continental country with an extreme type of Mediterranean climate. Over the greater part of its area the natural vegetation of forest and scrub was long ago destroyed to make way in classical times for agriculture of a conservative type which later gave place to wasteful practices of haphazard cultivation and extensive grazing. The remaining vegetation on steep slopes and the terraces which held up the soil of the hill farms were gradually destroyed, and the hills consequently denuded of soil. Stream-beds in the plains were filled up by transported gravel and silt, and the resultant formation of swamps was accelerated by the building-up of sand-dunes following the destruction of the vegetation on the coastal strip.

Prior to the war civil disturbances and financial stringency made it impossible to initiate any major schemes of soil conservation, but the value of terracing was demonstrated in the nurseries and stations of the Department of Agriculture, whilst two small schemes were inaugurated by the Department of Forests for the control of erosion by afforestation and the protection of the natural vegetation. Work on the control of sand-dunes was started at Gaza, and investigations were made into the growth of certain hardy species on eroded sites. Interest in erosion problems and remedial methods and awareness of its dangers were stimulated by the visit in 1939 of Dr. W. C. Lowdermilk, who spent many weeks visiting eroded sites.

A Soil Conservation Board under the chairmanship of the Conservator of Forests was set up by the Government in 1940. Discussions of the Board and their inspections of eroded land revealed the need of new legislation for the control of erosion as a prelude to any effective action. Terracing on agricultural land in the hills was extended during 1940, aided in some places by Government loans, and efforts were made to encourage contour ploughing. In May 1941 the Flooding and Soil Erosion (Prevention) Ordinance No. 12 of 1941 was passed by the Palestine legislature. The High Commissioner was empowered to declare regions threatened by erosion to be Special Areas in which the cultivation of crops, the pasturing and passage of domestic animals, and the cutting and removal of vegetation could be regulated or prohibited as circumstances required. The first Special Area to be declared was at Tiberias to the west of the Sea of Galilee. During 1941 one section of this area was trench-terraced at Government expense. It is intended to proceed section by section until, in the fifth year, the whole of the Special Area will be closed to grazing and subjected to soil-conservation restrictions. The work of the Board during 1941 also included the preparation of plans for the control and utilization of sand-dunes, the

framing of a proposal for a long-term scheme of regeneration for the Nablus-Tulkarm Valley, and the investigation of the problem of grazing.

Lack of control over grazing is stated to be by far the most important cause of flooding and soil erosion in Palestine, and the formulation of a grazing policy is under consideration. The construction of new terraces on cultivated hill-sides started in certain localities during 1941, and large demands were made on the Government Nurseries for the issue of trees for windbreaks and other purposes. Owing to the war overcutting of local vegetation has inevitably continued, but, on the other hand, the realization of this fact has led to increased provision of funds for planting in Forest Reserves.

In 1942 a second Special Area comprising 14,000 acres of loose sand-dunes south of Jaffa was declared with the object of bringing the dunes under control and preventing further damage by sand drifts to adjacent lands. Grazing is to be regulated and suitable grasses planted to bind the sand.

Special attention was paid to propaganda and education in 1942, in order to take advantage of and to stimulate the obvious interest of many sections of the population in soil conservation.

Trans-Jordan.—Soil erosion in Trans-Jordan is widespread and has become more evident in recent years. It is due to the destruction of forests (which has been progressing for centuries), to overgrazing, to improper methods of cultivation, and to the failure of the peasantry to maintain the ancient terraces on the hill-sides.

The rapid, natural increase in the population during the last 20 years and the consequent need for additional cultivation and larger flocks has to a certain extent accelerated the process of soil erosion. The effects of this pressure of population are now, however, taking a form which is not entirely evil in relation to the problem. In the first place, the damage has become so evident in places as to compel the most conservative or feckless landowner to take stock of the situation. In the second place, the urgent need for additional land for cultivation is driving the cultivators to repair ancient terraces and to terrace new hill-sides.

The chief measure employed to combat soil erosion is to obtain, in the course of land settlement, and register as state domain, areas of land which are forested or which are suitable for afforestation. Once the land is state domain, the prevention of detrimental practice is simplified. By the end of 1942 510,981 dunums of land had been secured in this fashion.

The reafforestation of parts of these areas was begun before the war, and 11,000 dunums were fenced in and planted with Aleppo pine and acorns (*Quercus aegilops*). Since the war fencing material has become unobtainable and the work of replanting has had to stop for the time.

Three officials of the Department of Lands received a course in forestry and the control of soil erosion in Palestine, and are now explaining to the Trans-Jordan people the benefits of terracing and contour ploughing. There is evidence that their work is having effect.

West Indies and America

In the British West Indies the gravity of the position varies considerably in different dependencies. Soil exploitation in the past has led in some parts to serious erosion; but in recent years the dangers have been brought prominently to notice. Considerable efforts have been made to devise an agricultural policy which will increase crop yields and assist the conservation of natural resources, and as a part of this policy simple measures of soil conservation are being advocated. In consequence there has been a considerable increase of public awareness of the change; owners and occupiers of land are beginning to realize that there is much they can do to lessen soil erosion, and members of the legislatures are conscious of the duty which the present generation must hold for the future of the land.

In the Bahamas, Barbados, Bermuda, and British Guiana soil erosion is not serious. The arable lands of *Barbados* are normally almost entirely devoted to sugar-cane, a crop which of itself provides considerable protection, whilst the practice of planting in cane-holes affords protection against wash. In the hills of the Scotland district erosion occurs and is serious in some areas, mostly on land of small agricultural value. Experiments were started in 1941, with funds provided under the Colonial Development and Welfare Act, to ascertain effective means of studying erosion of the steep hill-sides in this district; a survey has also been carried out with a view to afforestation and rehabilitation of the area involved.

In *Bermuda* the hill-sides are normally covered with trees and grass; arable cultivation is restricted to level or slightly sloping ground; and the limestone soil is very porous. The soil structure and the extensive use of windbreaks prevent erosion by high winds. Isolated cases of severe erosion by water occur where hill-sides are cleared for cultivation or where they are overgrazed by live stock. In general, however, erosion is on so limited a scale and the territory so small that it is possible for the Department of Agriculture to note the places where it is liable to occur in serious form and to advise landowners as to measures necessary to check damage.

In *British Guiana* there is no soil-erosion problem on the frontal lands, which are cultivated with sugar-cane and rice. The ranching lands of the interior are so poor in fertility that overstocking is nowhere apparent. Promising experiments on the improvement of pasture are in progress at Ebini.

British Honduras.—Over the greater part of the country soil erosion is not serious. Even on fairly steep, abandoned clearings the rate of regeneration of forest growth is so rapid and vigorous that serious soil losses do not occur. The policy of the local Department of Agriculture is to introduce improved methods for the intensive cultivation of comparatively small areas of land, rather than to permit shifting cultivation of larger areas; this policy has been promoted by means of demonstration loans for rice production, and a guaranteed price for agricultural products. Satisfactory progress in the development of 'settled' agriculture

has also been achieved on communal farms established in relief of damage due to hurricanes and locusts; it was found that the settlements continued after the cessation of the payment of relief money.

The transitory nature of forest exploitation leaves little impression on the vegetation, and erosion occurs only on extraction roads cut on steep slopes. For long-term concession these roads are protected from erosion by cross ditching. A topographical map of the colony is in preparation from aerial photographs and it is proposed to use it for the reservation of protective forests on steep slopes and of productive forests on land unsuited for agriculture. Some sheet erosion is caused by shifting cultivation in regions of high rainfall and on the Mountain Pine Ridge, but it has not yet been found possible to carry out any soil-conservation work.

Jamaica.—Soil conservation received but little attention until recently, although the topographical and climatic conditions as well as the single-crop system of agriculture that everywhere prevails are highly conducive to erosion. The rapidly increasing density of the population requires that the productivity of the land (much of which is steeply sloping) should be maintained at its maximum if a reasonable standard of living is to be assured to the inhabitants, and it is now becoming realized that Jamaica cannot afford any further losses of top soil.

To arouse popular attention effective propaganda has in recent years been carried out by the Department of Agriculture, the Department of Education, and the Jamaica Agricultural Society, and, since the start of the war, large-scale demonstrations of soil-conservation methods have been carried out by the Food Production Board. Results have been so successful that the Agricultural Society has recommended the enactment of legislation to compel the adoption of soil-conservation measures. But work is still in the experimental stage, and much investigation will be necessary before the most suitable methods of treatment are evolved for the various soil types and different climatic conditions.

Progress has been made, and a series of simple and practical instructions in conservation methods, which cultivators themselves can apply, has been published in the *Journal of the Jamaica Agricultural Society*. The measures recommended include the natural establishment of terraces by the packing of stones on walls along contours, the planting of grass strips along contours, strip-cropping, the use of mulches and catch crops, and the construction of contour drains on heavy soils in areas of high rainfall. So far visible progress is not very great, but interest and attention have been aroused and more rapid development is to be expected. The soil-conservation campaign will not be fully effective, however, until the accumulating fertility of the demonstrations is seen to produce superior yields of crops. The work has been facilitated by the acquisition of several estates for use as agricultural training centres to relieve unemployment.

Forestry activities have increased following substantial grants from Colonial Development and Welfare Funds. The worst sections of 10,000 acres of degraded land in the catchment areas of important rivers have been acquired for afforestation under the Taungya system, anti-

erosion practice being enforced. New roads through forestry plantations are laid out, drained, and protected to avoid gullying.

Leeward Islands (*Antigua, Montserrat, St. Kitts-Nevis and the Virgin Islands*).—Soil erosion is a serious problem and the effects of past negligence are plainly seen. In *Antigua* erosion in sugar-cane cultivation is more prevalent than was previously thought possible, and a system of contour banking is now being devised. Soil losses in peasant cotton and food-crop cultivation are considerable, particularly on hill-sides. A substantial increase in cultivation on steep hill-sides has occurred in recent years, mainly as a result of peasants extending cotton-growing in view of the favourable market, and for the increased production of food, which resulted in serious soil erosion. Good headway is being made, however, mainly with lines of khus-khus and Guatemala grass, and the anti-erosion demonstration plots on hill-sides are now after 4 years giving yields greatly superior to the unprotected lands.

During 1941 a Forestry Ordinance was enacted which declared all forested lands to be forest reserves within which the felling of trees is forbidden except under permit. Powers also exist under the ordinance for the reservation of denuded areas to allow of natural regeneration. This law has checked the deforestation of the hill-sides, which has been marked during recent years.

In *Montserrat* erosion is a serious and urgent problem. The principal export crops are sea-island cotton and tomatoes, both of which may cause serious soil erosion when grown on sloping lands without proper protective measures. The position is most serious on the higher lands where steep slopes have been denuded of their natural vegetation. Comprehensive proposals for dealing with the problem were made by the Inspector General of Agriculture, including the appointment of additional agricultural staff and the establishment of centres for investigating and demonstrating conservation methods. Planters are taking an active interest in the work, and it can now be claimed that most land in Montserrat is ridged on the contour.

In *St. Kitts* conditions are naturally favourable to erosion: much of the land is steeply sloping, the soil is light and friable, and the rainfall fairly heavy. The lower slopes of the island are mainly under sugar-cane, which has preserved most of the land on sugar estates where anti-erosion measures are practised to some extent. Marked sheet erosion, however, occurs on lands between the upper limit of cane cultivation and the lower limit of the forest belt, which are given up to labourers' food plots, and conservation measures are necessary. Appreciable progress has been achieved during the past two years. Contour cultivation has been adopted by several sugar estates in St. Kitts, and many managements and overseers are now equipped with road-tracers. The use of pen manure for the maintenance of soil fertility is still the practice on all estates, and the Central Basseterre Sugar Factory returns all residues and surplus bagasse to cane producers for application to the land. Satisfactory progress has been achieved with contouring the Fahies and Sadlers settlements. Experiments of the Matengo (Lake Nyasa) pit-system have been laid down. Two instructors were appointed to

assist peasants regarding anti-erosion methods on the upper provision lands.

In Nevis soil erosion is not a serious danger. Much of the sloping hill-lands are uncultivated and carry a heavy cover of vegetation, whilst the presence of numerous stones and boulders reduces erosion risks. Contouring with dry-stone walls is the simplest method of checking soil-wash under Nevis conditions, and this system has been evidently adopted by cultivators, who are largely of the peasant class. Contour cultivation by peasants has increased in recent years and more attention is being given to the maintenance of soil fertility. The Agricultural Department gives assistance with the laying down of contours on allottees' plots on Government land-settlement areas.

Trinidad and Tobago.—In Trinidad and Tobago soil erosion in varying degrees of severity has been going on for many years. The problem, if recognized, was shelved, but the stage has now been reached when energetic measures are essential for the welfare of the islands. The need for erosion control has been stressed in the report of the Trinidad Agricultural Policy Committee recently published.

It is mainly insidious sheet erosion that is variably affecting both sloping ground and flat alluvial lands. In addition, clay soils within wet areas are subject to land-creep and landslip. In the Northern Plain the effects of erosion are not spectacular, though every flooding rainstorm exacts its toll of surface-soil and the watercourses of the Oropouche and Caroni drainage systems are silt-laden throughout the wet season. In the Central Range land-creep and landslip movements are seen to some extent. In the hilly sugar-cane lands of the Southern Plain soil erosion has been enhanced by ploughing with heavy tractor-drawn implements, and the forest and cacao lands of the eastern and southern parts of the plain also show some sheet erosion; a large-scale demonstration (44 acres) of contour planting of sugar-cane has been laid down.

The Southern Range and Cedros Peninsula are mostly under forest; the loose sandy soil which covers their greater part erodes rapidly when exposed by tree-felling and burning.

Erosion in Tobago at present is important chiefly in the Castara and Mason Hall districts. Within the Windward cacao belt intensive erosion during the sugar-cane-growing era has effected considerable profile truncation in the hilly igneous rock soils that had originally developed under forest.

Soil conservation in Trinidad and Tobago has not yet been systematically practised, and the co-operation of planters and landowners is essential in any attempt to stop further degradation.

As a result of the report by the Lands Advisory Committee on the western foot-hills of the Northern Range the sum of $60,000 was provided in the 1942 Estimates to acquire 806 acres in the Caura Hills for the purpose of soil conservation. This is only a small part of the area necessary to protect the natural resources of soil and water in the Western portion of the Northern Range. Stringent measures have also been taken to tighten up fire-control, particularly in the Northern Range.

Windward Islands (*Dominica, Grenada, St. Lucia, St. Vincent*).—The

degradation of soil on cultivated slopes of land subject to high rainfall is the most complex problem of agriculture in the Windward Islands. The most serious consequences are to be seen in St. Lucia, where a heavy intractable subsoil is exposed within a few years of cultivation without anti-erosion measures; eroded land is then lost to agriculture almost indefinitely. In Dominica where the greater part of the island should be maintained in forest, the problem is not acute because of the sparsity of population. The most spectacular forms of soil erosion occur in St. Vincent; fortunately, however, the subsoil rapidly weathers and eroded lands are quickly brought back into a productive condition. Landslides, extensive gullying, and wash-aways in the high-rainfall areas regularly cause extensive damage to property, highways, and sometimes to life itself. The local Departments of Agriculture, especially those of St. Vincent and St. Lucia, have made considerable progress during the last two years both in awakening the public to the dangers of soil erosion, and in obtaining a good response from planters and small cultivators. The principal measure is the contour planting of grass bunds. A dual purpose is attained by the planting of Guatemala grass by the stock-owners, and the use of khus-khus grass where straw-plait cottage industries are developed. In St. Vincent they have passed the 'contouring' stage, and strip-cropping is the vogue. In the dry island of Carriacou, the ill-effects of soil erosion have had greater social consequences even than in St. Lucia.

A great deal of research on soil-conservation measures is needed in all the main ecological areas of the West Indies. Provision has been made for this in proposals which have been submitted jointly by the Principal, Imperial College of Tropical Agriculture, and the Inspector General of Agriculture, for the centralization of long-range research. At the same time there are some simple practices which can be safely applied in every colony. It is claimed that Departments of Agriculture have made much progress; agricultural officers and producers have profited by their early but not serious mistakes. The main obstacle to further advance has been shortage of tyres and petrol and, in some colonies, the demand for labour on important defence works. In all the islands of the British West Indies provision has been made by the Comptroller for Development and Welfare for financial assistance to carry out the programmes of soil conservation.

Falkland Islands.—The Falkland Islands consist of a group of two large and about 200 small islands. They contain a series of sloping plains traversed by mountain ranges, their total area is about 4,600 sq. miles, the soils are poor and the climate is colder on the average than that of the British Isles, although the annual temperature range is less. The annual rainfall is about 30 in. The islands are constantly swept by high winds. There are no forests and but few trees, the main vegetation being poor native grass and sedge. The only agricultural industry is sheep-raising, which is practised on rather primitive lines.

Water erosion does not occur to any appreciable extent, but considerable wind erosion takes place in a few localities where excessive grazing and burning have so weakened the turf that the top-soil is blown

away; damage has also occurred in certain areas where drifting sand has buried pasture vegetation. The worst effects are seen in coastal areas where uncontrolled grazing has killed the Tussock Grass (*Poa flabellata*). Some wind erosion occurs on dry ridges typically covered with goose-grass (*Aira praecox*) or on those locally known as diddle-dee ridges.

The erosion is not rapid, and may be prevented by fencing, so that grazing may be controlled, thus permitting the re-establishment of Tussock Grass in the coastal areas and the development of Brown Top (*Agrostis tenuis*), *Poa pratensis*, White Clover (*Trifolium repens*) pasture on the ridges.

Drifting sand can be controlled by planting marram grass or the native sand grass. Some attempts to improve matters by systematic grass-planting were begun in 1920. Later the matter received increased attention mainly with the object of improving the grazing and the low stock-carrying capacity of the grazing areas. In 1938 a visit was paid to the colony by Mr. W. Davies of the Welsh Plant-Breeding Station, the cost being met from funds provided under the Colonial Development Fund Act. In his report Mr. Davies indicated lines which would probably be effective in improving pasture conditions, and recommended extensive trials of certain methods of pasture improvement and the introduction of various grasses. Work has since been in progress in accordance with his recommendations.

Dependencies in the Western Pacific

Fiji.—Little damage from soil erosion occurs in the alluvial flat land of Fiji, but sheet erosion does take place on the undulating and high lands where the system of agriculture adopted by the Indian peasant is to cultivate one crop until the soil is exhausted and then move to another piece of land. No measures are taken to conserve the soil. The Fijian, on the other hand, shifts his cultivation at frequent intervals and seldom clean-weeds his crops. Though not commendable it does allow of a fairly quick regeneration of vegetation. Soil erosion also arises from the indiscriminate burning of grass and reed lands. Efforts have been made by the Department of Agriculture to demonstrate soil-conservation measures on their own demonstration farms and at provincial and other school farms. Eighteen such demonstration centres were started in 1939. The work has been continued since then, but its scope has been restricted owing to the preoccupation of the department with the campaign for the extension of food production.

In 1940 a Native Land Trust Ordinance was enacted which requires lessees of native land to apply and maintain such measures to check soil erosion as may be prescribed, and prohibits the clearing and cultivating of very steep slopes and stream banks.

Increasing attention has of late years been paid to the prevention of grassland burning in the dry zone. Propaganda has been undertaken pointing out the dangers of erosion and indicating simple preventive measures with the object of awakening public interest and preparing the way for a more intensive campaign as soon as circumstances permit.

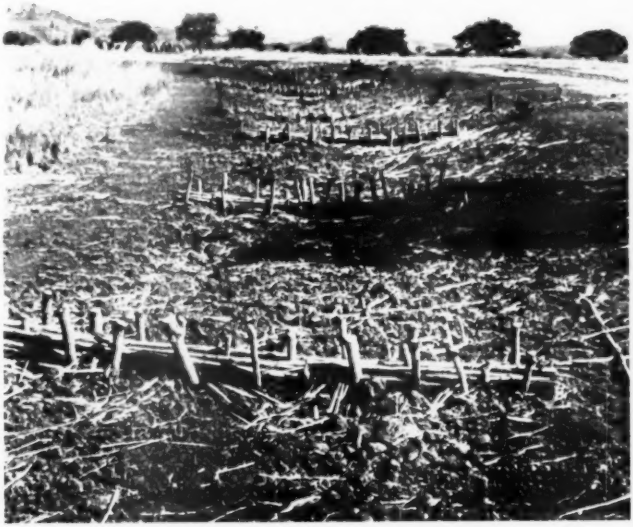
Basutoland. Shows the complete denudation and donga erosion that existed when the conservation measures illustrated were undertaken in 1936. See below.

The same area as above at the end of 1940. Grass has reappeared and trees planted in 1936 are beginning to make good growth.

Swaziland. Napier grass strips (prior to cutting back for fodder) used to check sheet erosion.

Shows sheet and donga (gulley) eroded area undergoing reclamation. Contour ploughing is clearly illustrated in the foreground.

Gold Coast. Incipient gulley erosion in over-grazed valley (Zuarungu district).



Gold Coast. Gulley Control. Stake and guinea-corn stalks used to check the rate of water-flow (Kusasi district).

Aden. Making a large sand-bank in the Wadi Bana to deflect flood water to some 2,000 acres of farming land.

Aden. Ploughing terraced fields. Crops of sorghum in the background.

Cyprus. Messoyi erosion area, showing contour stone-wall bunds.

Cyprus. Gulley erosion control.

Conclusion

Although soil erosion remains one of the chief agricultural problems with which the Colonial Empire is faced, it is a striking fact that notwithstanding war conditions there has been a marked gain in popular appreciation of the serious nature of the position, coupled with appreciable advances in the devising and application of soil-conservation measures. It cannot of course be said that anything approaching a satisfactory solution of the problem has yet been achieved, but the fact that so much advance has been capable of attainment in the midst of the anxieties and preoccupations of war appears to hold out hopes that with the return of peace the way may be open for achievements on a larger scale.

An important factor has been the provision of funds from the Imperial Treasury through the Colonial Development and Welfare Fund for carrying out soil-conservation measures; equally important has been the tendency towards improved collaboration between the various agencies of Government concerned with the different aspects of the question and the growing measure of popular support for policies directed towards conservation.

Acknowledgement

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CORRECTION FOR TIME OF SERVICE IN LACTATION RECORDS FOR A FIXED PERIOD

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FOR proper comparison of the milking capacities of different animals it is necessary to make due allowance for the differing circumstances in which their lactation records may have been established. Simplicity in application is a desirable property of such corrections; a high degree of accuracy is not only unnecessary but, owing to the number of factors for which no allowance can be made, is also futile.

Sanders (*J. Agric. Sci.*, 1927, **17**, 502), working on records from milk recording societies, has made an extensive study of and gives the corrections to be applied for, month of calving, age and lengths of service, and dry periods. However, he has used the total lactation yield in making his calculations and not, as is found practically more convenient and desirable, the yield over a standard period; his corrections are not therefore immediately applicable when such a standard is adopted.

Sanders gives (Fig. 1) the decline in yield due to the incidence of pregnancy apart from that caused by the progress of lactation. He comments: 'After pregnancy has commenced the yield settles down at a definitely lower level than before; this reduction amounts to less than a gallon a week, but appears to be quite definite and continuous for the first 20 weeks of pregnancy, when the fall suddenly becomes very steep.' Delay in service so that this latter phase of lactation falls outside the standard lactation period therefore gives a considerable advantage in yield, an advantage which is not proportionately increased by further extension of the service period.

Sanders's data were derived from two sources; taking certain intermediate values (shown in Fig. 1) and interpolating between them, a curve (Fig. 2) has been constructed from these figures showing the total loss in yield with the progress of gestation. By suitable adjustment of the position of the origin, the curve also shows the correction to be made to adjust to a service period of 85 days (if the S.P. exceeds this value) and a standard lactation of 305 days. These values have been chosen as seeming most convenient, since an 85-day S.P. implies calvings at an interval of one year, and 305 days lactation then allows for a 2-months dry period.

Also shown in the figure is a suggested method of correction to the given standard. This is of a very simple nature and, assuming the accuracy of the curve, the error involved is at the most about 4 gallons and generally much less than this. The simple corrections to be deducted from the actual yield of the lactation to obtain the standardized yield are in pounds:

Calving up to 70 days late, or S.P. between 85 and 155 days
$5 \times$ days late or $5 \times$ (S.P. in days $-$ 85).
Over 70 days late, or S.P. over 155 days
280 + days late or 195 + S.P. in days.

For calving 4, 8, 12, 16, and 20 weeks late the corrections then are, respectively, 140 lb., 280 lb., 364 lb., 392 lb., and 420 lb., for a standardized yield of 6,000 lb.

The correction to be applied is given in terms either of the Service Period or of the interval between calvings; clearly the former is much to be pre-

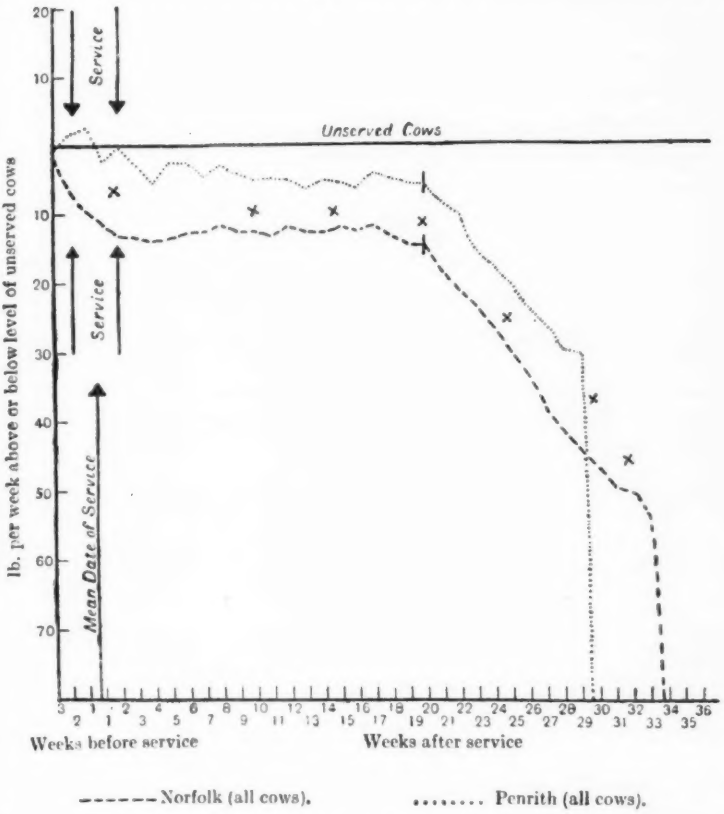
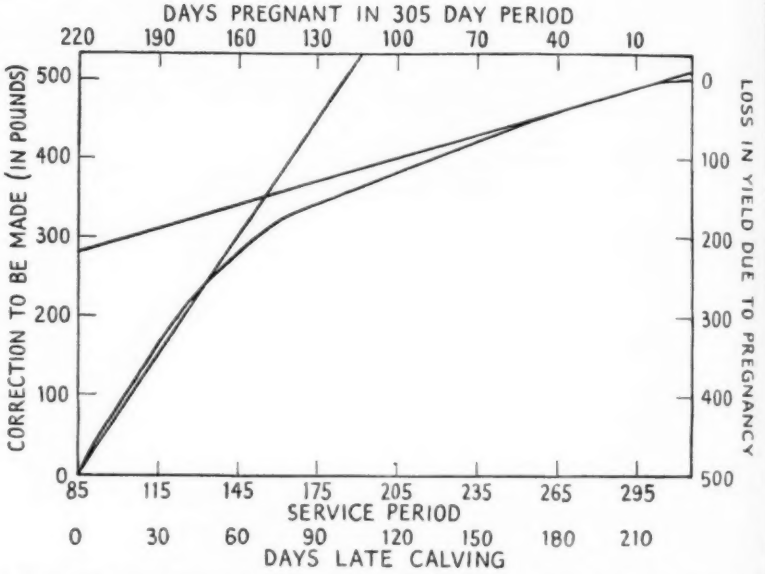


FIG. 1. Figure from Sanders, showing decline in yield due to pregnancy, and (×) points taken in constructing Fig. 2.

ferred, since by the latter method, in the event of a premature calving, the cow is wrongly credited—at a rate of reduction in yield which she never suffered in the standard period—with that period of time pregnant by which she calves prematurely.

The levels of lactation (corrected to an 85-day S.P.) of the two groups of cows from which Sanders gives the data of Fig. 1 would appear to be about 5,400 lb. (Penrith) and 6,700 lb. (Norfolk). In obtaining the curve given in Fig. 2, intermediate values were taken for drop in yield; the

corrections given therein should therefore apply to a (corrected) lactation of about 6,000 lb. Sanders found that when the declines in yield for the two groups were expressed, not as an absolute amount, but as a percentage of the yield of unserved cows, the two curves were nearly the same. It would appear therefore that such corrections can be adjusted to other levels by altering the correction proportionately to the (corrected) level of lactation.


DAYS PREGNANT IN 305 DAY PERIOD
220 190 160 130 100 70 40 10
CORRECTION TO BE MADE (IN POUNDS)
500 400 300 200 100 0
LOSS IN YIELD DUE TO PREGNANCY
0 100 200 300 400 500
85 115 145 175 205 235 265 295
SERVICE PERIOD
0 30 60 90 120 150 180 210
DAYS LATE CALVING

Corrections for late calving: up to 70 days late, deduct (lb.) 5 × days late; over 70 days late, deduct (lb.) 280 and days late. *Or*: up to S.P. 155 days, deduct (lb.) 5 × (S.P. − 85). S.P. over 155 days, deduct (lb.) (S.P. + 195).

FIG. 2. Total loss in yield at different stages of pregnancy and a suggested simple method of correction.

It is not suggested that the curve given (Fig. 2) is the best that can be derived from Sanders's data, nor that the simple corrections given would be practically the most satisfactory. In view, however, of the interest at present attaching to this matter, it seemed worth while to outline the nature of the problem, and of the type of correction which will be needed.

(*Received March 6, 1944*)

EFFICIENCY OF DESIGN IN FIELD EXPERIMENT AT POTCHEFSTROOM, SOUTH AFRICA

A. R. SAUNDERS

THE newer statistical methods developed by Fisher and his associates have profoundly influenced agricultural experimentation, especially in the agronomic field, and have contributed in very liberal measure to more effective and fruitful investigation. But the classical randomized-block and Latin-square designs have their limitations when the number of treatments or varieties to be tested is relatively large, the latter because it then becomes cumbersome and the former because it loses efficiency when the block-size is so large that the error variance is unduly inflated by uneliminated intra-block soil variability.

More recently Yates [1–5] has developed several methods by which complete replications can be divided into sub-blocks, each containing a smaller number of treatments than the total under test. These methods fall into four main classes: (*a*) partial or total confounding of certain interactions in factorial experiments with block effects, (*b*) quasi-factorial or lattice designs, (*c*) quasi-Latin or lattice squares, and (*d*) balanced incomplete block arrangements. A fifth method, by which economy of space may be effected or the accuracy of certain comparisons increased, is the use of split-plots. Here block-size may be reduced by having the sub-plots of smaller size than is normally used in complete randomization, or the number of replications may be reduced at the cost of sacrificing accuracy on main-plot comparisons [5].

Confounded arrangements, although very useful in experiments of a preliminary or exploratory nature, are not without disadvantages and have been employed at this station to a very limited extent only. One of many instances of a $3 \times 3 \times 3$ arrangement, in 3 blocks of 9 plots, without replication, has already been reported by the writer [6], and the method doubtless deserves of wider application. The greatest objection to it is that with the more involved designs the analysis of the data is complicated and that an error in field layout or execution of an experiment might vitiate the results entirely.

Review of Literature

The various procedures for determining the relative accuracy of particular designs in relation to that of ordinary randomized blocks have been fully described in the literature and are therefore not repeated here [1–5, 7–14]. In his first exposition of the lattice design, Yates [2] found a gain of 26 per cent. to 57 per cent. in efficiency over the randomized complete-block. A lattice-square design superimposed on a uniformity trial with oranges yielded a gain of 91 per cent. in precision over randomized blocks. Goulden [13, 14] obtained marked increases in efficiency from both lattice and balanced incomplete block designs. Weiss and Cox [15] demonstrated a 150 per cent. increase in efficiency in one lattice-square design and a loss of 31·5 per cent. in another. They concluded

that the incomplete block designs, including the lattice and lattice square, showed to greatest advantage when the number of varieties was large and the soil heterogeneous.

In the above experiments no account was taken of the information contained in the comparisons of the group means. The recovery of this inter-block information overcomes one weakness of the incomplete block designs, viz. that on a uniform soil they may be appreciably less accurate than randomized whole-blocks, owing to the number of degrees of freedom absorbed by the sub-blocks. Depending upon the relative accuracy of the intra-block and inter-block comparisons the gain in precision may be trivial or very considerable [7–10]. In an extensive examination of uniformity-trial data, Zuber [16] found an average gain in efficiency of 25 per cent. from incomplete block designs. With recovery of inter-block information this value was raised to 36 per cent. The lattice-square design gave the greatest average gain in precision, followed by the balanced lattice, lattice, and triple-lattice designs. In no case did the recovery of inter-block information fail to show a gain in accuracy over randomized blocks.

Wellhausen [17] reported a gain of 44 per cent. in accuracy over randomized blocks in a series of 60 maize co-operative varietal trials designed as balanced lattices with 9 varieties and 4 replications. The 4 replications in balanced lattices were on an average as accurate as 5 or 6 replications in ordinary randomized blocks. He also obtained noteworthy gains from 5×5 and 7×7 lattice-square designs.

Experiments at Potchefstroom

The soil of the experimental area is a sedimentary reddish-brown loam, about 12 in. deep, and characterized by high general uniformity. The main experimental block, some 60 acres in extent, is divided into ranges 22 yds. wide and the plots lie across the ranges. A standard plot-width of 7 yds. has been adopted almost throughout and a border strip 1 yd. wide is removed round the entire plot at the time of harvest, thus leaving a net size of 1/100 morgen or approximately 1/48 acre. All planting is done by hand at an excessive rate of seeding, and after germination is complete, the stand is thinned to the required density. Weeds are rigorously controlled and every possible precaution is taken to eliminate such sources of variation as are under human control.

Nearly all 'permanent' experiments, such as fertilizer trials, are laid down in randomized whole-blocks, in some cases with split-plotting, whilst the incomplete block designs have almost exclusively been used in variety trials only. The data presented in the following tables have been obtained over a period of 12 years, commencing with the layout of a new experimental block in 1930.

Lattice designs.—Table 1 shows the results from 10 simple unbalanced lattice designs with k^2 treatments. The sub-blocks were compactly arranged in randomized whole-blocks or replications, with, of course, the necessary restrictions to complete randomization imposed by the design. The trials occupied different sites in the experimental area, and, although plot-size varied for different crops, it was kept constant for the

same crop. In this and subsequent tables relative efficiency of the design, with recovery of inter-block information, is given in comparison with that of randomized blocks as unity.

TABLE 1. *Efficiency of Lattice Designs*

Experiment	*k*	*r*	*Efficiency*	*Harvest*
1. Maize varieties	4	4	1·49	Grain
2. ,, ,,	4	4	1·14	Ensilage
3. Soya-bean varieties	6	4	1·54	Seed
4. ,, ,,	6	4	1·43	Seed
5. ,, ,,	6	4	1·15	Hay
6. ,, ,,	6	4	1·14	Hay
7. ,, ,,	4	4	1·36	Seed
8. ,, ,,	4	4	1·10	Hay
9. ,, ,,	7	2	1·04	Seed
10. Cowpea varieties	5	4	1·53	Hay
Mean	..	..	1·29	..

k = number of varieties per block; *r* = replications.

In 5 out of the 10 experiments there was no gain in efficiency with the use of the lattice design when the inter-block information was not recovered. Recovery of this information yielded a gain in accuracy in all cases, although in some instances it was not appreciable. Without recovery the average gain was 15 per cent., a comparatively low figure. Although no definite conclusions can be drawn from such a small number of trials it would appear that even on a relatively uniform soil the use of lattice designs may have considerable advantage provided the inter-block information is recovered in the analysis.

Balanced Lattices.—Five balanced lattice designs, 4 with 16 varieties and one with 25 varieties, gave the following results:

TABLE 2. *Relative Efficiency of Balanced Lattice Designs*

Experiment	*k*	*Efficiency*	*Harvest*
1. Soya-bean variety trial	4	1·02	Seed
2. ,, ,,	4	1·05	Hay
3. Cowpea variety trial	4	1·57	Hay
4. ,, ,,	4	1·14	Hay
5. Maize variety trial	5	2·82	Grain
Mean		1·52	..

Both soya-bean variety trials and the second cowpea trial were located on the same site, one of known high soil uniformity; the first cowpea trial occupied a series of plots the uniformity of which had been somewhat disturbed by preceding trials. In the randomized-block analysis of this experiment the variance ratio fell slightly short of the 5 per cent. level of significance, whereas in the lattice analysis it approached the 1 per cent. level. The maize variety trial yielded a highly significant

variance ratio even in the randomized-block analysis, but in spite of this the lattice design gave a marked increase in efficiency.

If the sub-blocks are so grouped that an ordinary randomized-block analysis can be made there is certainly nothing to lose and possibly something to gain from the use of this design. Since the layout is straightforward and the analysis of the data relatively simple, the design has much to commend itself and is undoubtedly of great value on soils of known high variability. Its most serious disadvantage is that, for its most convenient form, the number of varieties or treatments must be a square.

Lattice squares.—The lattice-square design stands in the same relation to the simple lattice as the Latin square does to the randomized block, that is, it allows of the elimination of soil variation in two directions by the sub-blocks. So far the design has been employed in 4 experiments, each with 25 varieties and 3 replications.

TABLE 3. *Efficiency of Lattice Square Designs*

Experiments	*Efficiency*	*Harvest*
1. Cowpea varieties	1·26	Hay
2. ,, ,,	3·83	Hay
3. Soya-bean varieties	1·64	Seed
4. Maize variety trial	2·64	Grain
Mean	2·34	..

The average increase in efficiency is considerable, and very large in the second and fourth trials. From previous knowledge of the soil variability this was to be expected, for the yields from preceding crops had shown that the main blocks occupied by the three replications in these two trials did not differ as much in total yielding capacity as separate parts within each. In fact, prior to the adoption of the lattice-square layout, the soil was regarded as too variable for reliable experimentation except with small blocks, and for several years it was used solely for seed multiplication.

Balanced incomplete blocks.—The development of the balanced incomplete-block device has to a considerable extent overcome the difficulty of lattice designs in requiring that the number of treatments shall be a square. The former is bound to become more and more useful as further combinatorial solutions are arrived at. In the following table are given 5 trials conducted during the past 6 years.

TABLE 4. *Relative Efficiency of Balanced Incomplete Block Designs*

Experiment	v	k	r	*Efficiency*	*Harvest*
1. Wheat variety trial	21	5	5	1·84	Grain
2. Sorghum variety trial	13	4	4	1·06	Ensilage
3. ,, ,,	11	6	6	1·29	Ensilage
4. Maize variety trial	10	4	6	1·47	Grain
5. ,, ,,	6	3	5	1·19	Grain
Mean	..	..	..	1·37	

v = varieties; k = number per block; r = replications.

Although results varied considerably they showed a notable gain in efficiency in 3 out of the 5 trials, despite the fact that all the trials were located on soil which is probably much above the average in uniformity. With large numbers of varieties the gain in efficiency might conceivably have been greater. The added increase in accuracy from recovery of the inter-block information was relatively less than in the case of the lattice designs.

Split-plot arrangements.—From the point of view of convenient handling in the field, split-plot layouts have been found most advantageous in factorial experiments, but at the same time it has been possible to limit the area devoted to each experiment by reducing either the size of sub-plot or the number of main-plot replications.

TABLE 5. *Efficiency of Split-plot Arrangements*

Experiment	*No. of trials*	*Treatment and No. of main-plots per block*	*Treatment and No. of sub-plots per main-plot*	*Replications*	*Efficiency*	
					Main-plot comparisons	*Sub-plot comparisons*
1. Maize variety and spacing	2	Var. (6)	Spac. (5)	4	0·344	1·697
	4	Var. (2)	Spac. (6)	5	0·269	1·662
	2	Var. (2)	Spac. (5)	5	0·353	1·468
	2	Spac. (2)	Var. (6)	4	0·333	1·488
	2	Spac. (2)	Var. (5)	3	0·390	1·250
2. Soya-bean variety and spacing	3	Var. (4)	Spac. (4)	2	0·485	1·788
	1	Var. (4)	Spac. (4)	4	0·422	1·522
	2	Var. (5)	Spac. (5)	4	0·481	1·432
	2	Var. (2)	Spac. (4)	4	0·435	1·272
	1	Spac. (4)	Var. (4)	2	0·333	1·475
3. Cowpea variety and spacing	1	Var. (5)	Spac. (3)	5	0·408	1·772
	1	Var. (2)	Spac. (3)	5	0·508	1·320
	1	Spac. (3)	Var. (5)	3	0·635	1·106
4. Crops, date of planting	1	Dates (3)	Crops (10)	4	0·123	2·129
5. Fodder crops and spacing	1	Spac. (3)	Crops (5)	4	0·323	1·537
6. Fodder crops and date of planting	1	Dates (3)	Crops (10)	3	0·685	1·035
7. Hay crops and seeding-rate	1	Crops (6)	Rates (5)	4	0·225	3·551
8. Green manures and phosphate	8*	Phosph. (2)	Greenm. (5)	5	0·499	1·221
9. Rotation and phosphate	8*	Phosph. (2)	Rotat. (5)	9	0·675	1·236
10. Sorghum variety and spacing	2	Var. (3)	Spac. (3)	2	0·292	5·242

* The same experiments over 8 years.

The loss of information on main-plot comparisons has in several instances been considerable, and the experimenter must naturally decide for himself whether the compensating gain on sub-plot comparisons is worth while. In the above experiments the main object was either the measurement of small differences between sub-plot treatments or of interaction values, and the loss of information on main-plot comparisons has been immaterial.

Summary

Data are presented on the efficiency of lattice, balanced-lattice, lattice-square, balanced incomplete-block, and split-plot designs.

Lattice designs gave an average increase in efficiency of 29 per cent., balanced lattices 52 per cent., lattice squares 134 per cent., and balanced incomplete blocks 37 per cent., with recovery of inter-block information. Split-plot arrangements resulted in a considerable loss of information on main-plot comparisons and an appreciable gain on sub-plot comparisons.

REFERENCES

1. F. YATES, The Principles of Orthogonality and Confounding in Replicated Experiments. J. Agri. Sci., 1933, **23**, 108–45.
2. —— A New Method of Arranging Variety Trials involving a Large Number of Varieties. Ibid., 1936, **26**, 424–55.
3. —— Incomplete Randomized Blocks. Ann. Eugen., 1936, **7**, 121–40.
4. —— A Further Note on the Arrangement of Variety Trials: quasi-Latin squares. Ibid., 1937, **7**, 319–32.
5. —— The Design and Analysis of Factorial Experiments. Imp. Bur. Soil. Sci., 1937, Tech. Comm. No. 35.
6. A. R. SAUNDERS, Statistical Methods with special reference to Field Experiments. Union S. A. Dept. Agric., 1939, Sci. Bull. No. 200.
7. F. YATES, The Recovery of Inter-block Information in Variety Trials arranged in Three-dimensional Lattices. Ann. Eugen., 1939, **9**, 136–56.
8. —— The Recovery of Inter-block Information in Balanced Incomplete Block Designs. Ibid., 1940, **10**, 317–25.
9. —— Lattice Squares. J. Agri. Sci., 1940, **30**, 672–87.
10. W. G. COCHRAN, An Examination of the Accuracy of Lattice and Lattice Square Experiments on Corn. Iowa, 1941, Res. Bull. No. 289.
11. GERTRUDE M. COX, R. C. ECKARDT, and W. G. COCHRAN, The Analyses of Lattice and Triple Lattice Experiments in Corn Variety Tests. Iowa. 1940, Res. Bull. No. 251.
12. R. A. FISHER, and F. YATES, Statistical Tables for Biological, Agricultural and Medical Research. Oliver and Boyd, 2nd ed. 1943.
13. C. H. GOULDEN, Modern Methods of Testing a Large Number of Varieties. Canad. Dept. Agric., 1937, Tech. Bull. No. 9.
14. ——Efficiency in Field Trials of Pseudo-factorial and Incomplete Randomized-block Methods. Canad. J. Res., 1937, **15**, 231–41.
15. M. G. WEISS, and GERTRUDE M. COX, Balanced Incomplete Block and Lattice-square Designs for testing Yield-differences among Large Numbers of Soya-Bean Varieties. Iowa, 1939, Res. Bull. No. 257.
16. M. S. ZUBER, Relative Efficiency of Incomplete Block Designs using Corn Uniformity Trial Data. J. Amer. Soc. Agron., 1942, **34**, 30-47.
17. E. J. WELLHAUSEN, The Accuracy of Incomplete Block Designs in Varietal Trials in West Virginia. Ibid., 1943, **35**, 66–76.

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THE MANURING OF FARM CROPS: SOME RESULTS OF A SURVEY OF FERTILIZER PRACTICE IN ENGLAND

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Introduction.—During the year 1942–3 a survey of fertilizer practice was carried out in three of the Ministry of Agriculture's Advisory Provinces in order to determine how different crops were manured under different circumstances. The work is being continued and extended during the year 1943–4.

The survey is a co-operative piece of work instituted by the Ministry of Agriculture, and executed by surveyors working under the direction of the Advisory Chemists of the Provinces concerned. The planning has been the joint concern of these Advisory Chemists and members of the staff of Rothamsted Experimental Station. The statistical analysis of the results has been the responsibility of the Statistical Department at Rothamsted, and the present report has been prepared by members of that department. Detailed reports of the results of the surveys in the different counties have already been prepared and issued in duplicate form.

The authors accept full responsibility for the views expressed in this report, but they would like to put on record the very great assistance that has been rendered at all stages of the survey and in the preparation of the various reports by the Advisory Chemists of the Provinces concerned, namely Mr. F. Hanley (Cambridge), Mr. A. W. Ling (Bristol), and Mr. H. Trefor Jones (Leeds), and also by Dr. E. M. Crowther (Rothamsted). Without this most active and constructive co-operation a survey of this magnitude and complexity would have been totally impossible.

The object of this report is to present some of the main findings of the survey which have immediate relevance from the point of view of improving the use of fertilizers. Except where otherwise stated, the report relates to the manuring of the 1942 crops.

The method of survey was as follows. In each of the surveyed counties an assistant of the Advisory Chemist visited a random sample of farms and obtained from the farmer detailed information on the manuring of the crops grown on the farm. For each crop one old arable and one new arable field was selected. Information on the manuring and cropping of the surveyed fields before 1942 was also sought. Soil samples were taken from one old arable, one new arable, and one grass field on each farm, and analysed for reaction and readily soluble P_2O_5 and K_2O. Between 40 and 120 farms were visited in each county.

The results have been summarized county by county, and where there is considerable variation in the type of agriculture in different parts of a county, the county has been divided into two or more districts. The

counties covered by the 1942–3 survey and their sub-divisions into districts are:

Province	*County*	*District*	*Description*
Cambridge	Norfolk	East	Loams
		West	Light sands & loams (fens omitted)
	Cambridge	East	Chalk
		West	Clays
	Bedford	East	Market-gardening area
		West	..
	Essex	North	..
		South	..
Bristol	Wiltshire	East	Chalk
		West	Clays
	Hereford	..	..
	Somerset	..	..
	Gloucester	East	Cotswolds
		West	Vale of Severn
Leeds	Yorkshire	Holderness	..
		Wolds	..
		Vale of York	..
		Pennines and North York Moors	..

The boundaries of these districts are shown on the maps which follow.

Although the chief object of the survey has been to collect information on the use of fertilizers, it has also provided an opportunity to assess the reliability and possible scope of farm-to-farm sampling surveys. Surveys of this type provide the only simple means of obtaining unbiased information on farm practice.

TABLE 1. *Comparison of Two Independent Samples of East Norfolk Farms*

(Average overall dressings in tons F.Y.M. and cwt. N, P_2O_5, and K_2O per acre)

	Sample	*No. of fields*	*F.Y.M.*	N	P_2O_5	K_2O
Wheat	A	36	4·7	0·14	0·18	0·00
	B	36	4·1	0·13	0·17	0·00
Barley	A	45	0·4	0·17	0·25	0·00
	B	45	0·1	0·20	0·21	0·00
Oats	A	41	1·4	0·15	0·09	0·00
	B	38	1·5	0·20	0·13	0·00
Sugar-beet	A	40	6·1	0·51	0·59	0·42
	B	36	6·4	0·48	0·44	0·33
Mangolds	A	33	5·9	0·34	0·39	0·10
	B	33	6·8	0·31	0·42	0·07
Swedes and turnips	A	16	4·9	0·25	0·30	0·04
	B	17	4·3	0·31	0·35	0·01
Temporary grass	A	44	0·0	0·01	0·00	0·00
	B	40	0·0	0·01	0·00	0·00

The reliability of the sampling method is illustrated by a comparison of the results of two parallel samples, each of about 55 farms, taken in the course of the Norfolk survey. Table 1 shows that although the informa-

tion for each crop covered a relatively small number of fields, a very satisfactory degree of accuracy has been attained.

Use of farmyard manure.—Before considering fertilizers it will be best to describe the use of farmyard manure. The use of these two main sources of plant nutrients can be described separately, since, although it might be expected that where farmyard manure is given the amount of

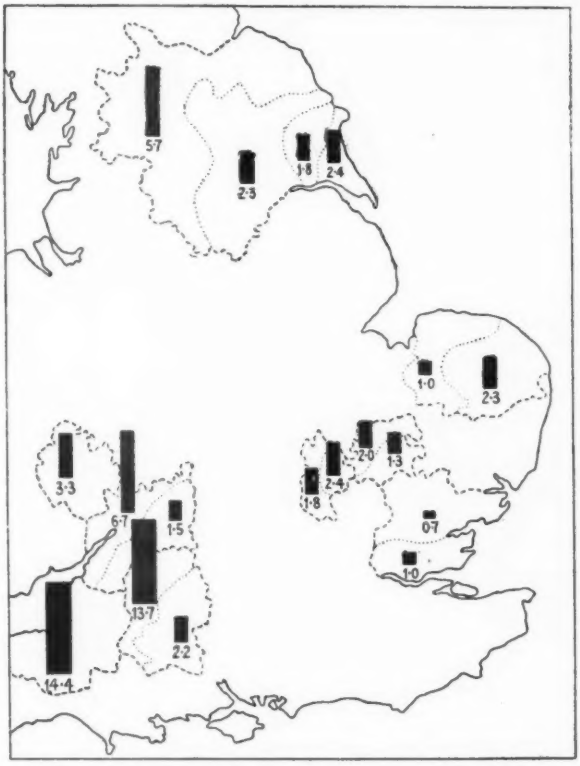

FIG. 1. Amount of farmyard manure used on farms.
(Quantities expressed in tons per arable acre.)

fertilizers will be reduced, the detailed results of the survey have shown that there is in fact little difference in the quantities of fertilizers applied to fields with and without farmyard manure (see p. 171).

Prior to the survey there was very little quantitative information on the production and use of farmyard manure in different parts of the country, though it was of course well known that dairying districts in general had a surplus, whereas only relatively small amounts were available in the arable districts. This difference is illustrated in quantitative terms in Fig. 1, which shows the quantity of farmyard manure produced per acre of arable land in each district. Although the amounts

shown in this diagram are not very reliable, owing to the difficulty of obtaining accurate information from farmers as to the actual amounts applied, the figure shows very clearly that under war-time conditions the supply of farmyard manure in some of the arable districts is very limited:

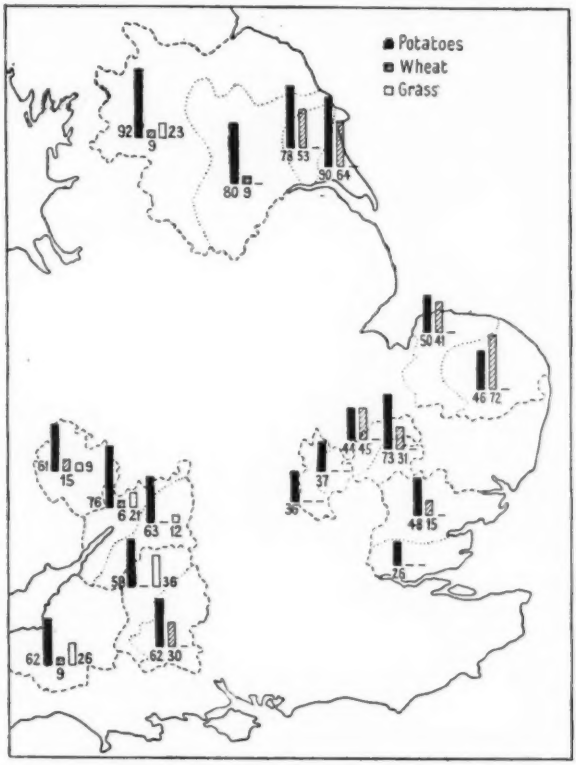

FIG. 2. Use of farmyard manure. (Percentage of acreage of potatoes and wheat grown on old arable land and of permanent grass receiving farmyard manure.)

in no case does the supply exceed 2½ tons per arable acre, and in three districts it is 1 ton per acre or less. The dairying and cattle-rearing districts, on the other hand, have large supplies of manure: the dairying districts of Somerset and West Wiltshire both have supplies of over 10 tons per arable acre.

Variations in the frequency of use of farmyard manure from district to district are illustrated in Fig. 2, which shows the proportions of the respective acreages of potatoes and wheat grown on old arable land, and of permanent grass, receiving farmyard manure.

From this figure it will be seen that only in the cattle-rearing and dairying districts was farmyard manure used on grass fields; in

Somerset one quarter and in West Wiltshire over one third of the grassland receives farmyard manure each year. The practice of dunging potatoes is most extensive in Yorkshire, where in all four districts 80–90 per cent. of all fields receive dung. The percentage is considerably lower in the Cambridge Province, partly owing to the limited supplies available and partly owing to the practice of dunging wheat. This practice is also prevalent in Holderness and the Yorkshire Wolds, and to a certain extent in East Wiltshire. Considering the amount of farmyard manure available a surprisingly small percentage of potatoes grown in the Bristol Province was dunged.

Further details of the frequency of use of farmyard manure on the various crops, and indications of the average dressings employed, are shown in Figs. 4 and 5. The average overall dressings are given for certain broad districts and for the whole of the surveyed area in Fig. 3. From these figures it will be seen that farmyard manure is rarely used on corn crops other than wheat. Mangolds are treated similarly to potatoes, but sugar-beet receives very little farmyard manure, except in the important sugar-beet district of East Norfolk and in Hereford. Swedes in general occupy an intermediate position between mangolds and sugar-beet.

It may be noted that although one-quarter to one-third of the permanent grass is dunged each year in the principal dairying districts, the soil analyses carried out in the course of the survey indicate that dairy husbandry has made a heavy drain on the fertility of the soils. Almost half the new arable land and grassland is low in potash, having 0·006 per cent. citric sol. K_2O or less, showing that the large amounts of farmyard manure spread on the grassland have been insufficient to balance losses from repeated haying (every two or three years is a common practice). In the absence of urine tanks a large part of the nutrients recovered in the hay is inevitably lost in drainage from the cow sheds.

Fertilizers.—The large number of fields for which fertilizer information has been obtained—several hundreds of each of the principal crops—enables an accurate statement to be made on the average rates of manuring in each province and in the individual counties. Again it was found, contrary to expectation, that crops grown on old arable land were manured very similarly to crops grown on recently ploughed-out grassland (see p. 172). Consequently there is no need to distinguish between the two categories in the presentation of the results.

Fig. 3 shows the average overall rates of manuring of the principal crops. The rates for the eastern counties, the Vale of York, the Pennines, and the western counties (excluding E. Wilts.) are also shown separately.

In 1942 a rationing scheme was in operation for phosphate and potash, and this limited the total amounts of these fertilizers available to the farmers. Potash was allocated to potatoes and sugar-beet at the rates of 0·6 and 0·4 cwt. K_2O respectively, and its use for cereals and fodder roots was forbidden, except on markedly deficient soils. There were no restrictions as to crops in the case of phosphate, and the actual method of allocation to farmers varied from county to county, though the distribution to the counties themselves was based on rates of 0·1, 0·7, and 0·5 cwt. P_2O_5 for cereals, potatoes, and other roots, respectively, plus an allowance

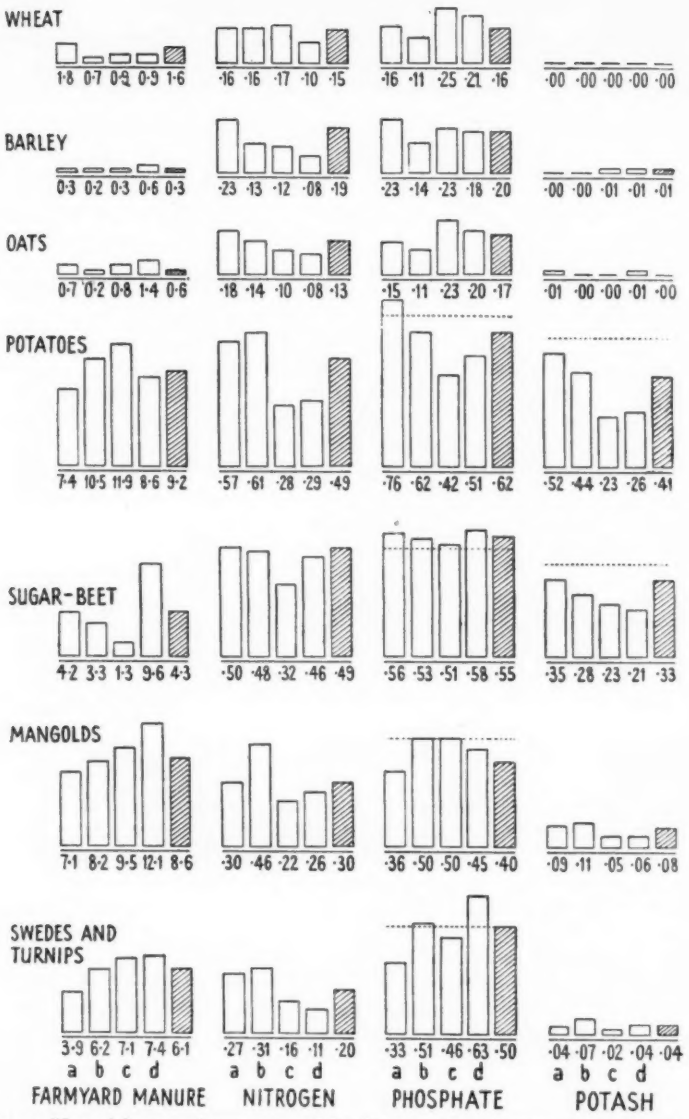

FIG. 3. Use of farmyard manure and fertilizers. Overall average dressings in tons F.Y.M. and cwt. N, P_2O_5, and K_2O per acre in (*a*) the eastern counties, (*b*) the Vale of York, (*c*) the Pennines, (*d*) the western counties, and in all surveyed counties (shaded). Dotted lines across diagram represent allocation to crop.

for deficient soils and land ploughed out since the war, these rates being chosen, on the basis of the results of fertilizer trials, as the ones which would give the maximum total food production with available phosphate supplies.

From the figure it will be seen that the general levels of phosphate manuring correspond to the distribution rates, though potatoes receive smaller amounts in the Pennines and western counties (where few potatoes were grown before the war). Mangolds and swedes receive least phosphate in the eastern counties. Phosphate applications to cereals are smallest in the Vale of York and highest in the Pennines and the western counties, though they are also high for barley in the eastern counties. The average rate for cereals is about 0·18 cwt., most of the allocation for deficient soils and newly ploughed-out land being used on cereals. Summarizing, the figure shows that there does not appear to be any general recognition of the higher phosphate requirements of the wetter districts.

In the case of potash, the average dressings of the two potash priority crops, potatoes and sugar-beet, approach the allocated rates only in the eastern counties. The average dressings to potatoes in the Pennines and the western counties are less than 0·3 K_2O. The fodder roots, particularly mangolds, have received small amounts of potash. Very little potash has been used on cereals.

In the case of nitrogen there was no limitation in supply, and in general farmers were in a position to obtain all they required. The average dressings of nitrogen varied considerably in the different parts of the country, being in general higher in the drier eastern districts, though the differences in rainfall do not fully account for the differences of practice.

The averages shown in Fig. 3 are useful as an indication of the general level of fertilizer practice, but they conceal marked variations in manuring from county to county and even between different districts in the same county. In addition, average values taken over all fields fail to show how far the use of any fertilizer component is general over all fields growing a given crop. Fig. 4 has therefore been designed to show the proportion of the crop acreage receiving any fertilizer component, and the average rate of application on fields receiving it. Fig. 5 gives the same information for each county and district (see folder at end). In Fig. 4 certain additional crops are included for which the information district by district is not sufficiently extensive to be worth separate presentation.

These diagrams show that the differences in the nitrogenous manuring of cereals shown in Fig. 3 are mainly due to variations in the proportions of the fields which are dressed in the different parts of the country. In almost all districts the average actual dressing (i.e. the average dressing on fields receiving nitrogen) varies between 0·2 and 0·3 cwt N. The only exceptions are West Norfolk and East Wiltshire, where the average actual dressings are somewhat higher. The detailed results of the survey showed that there was a tendency to withhold nitrogen, as well as phosphate, from cereals following a root crop.

The diagrams also reveal interesting differences in the use of phosphate on cereals. In North Essex and East Wiltshire, where combine drills are common, barley receives relatively small amounts of phosphate,

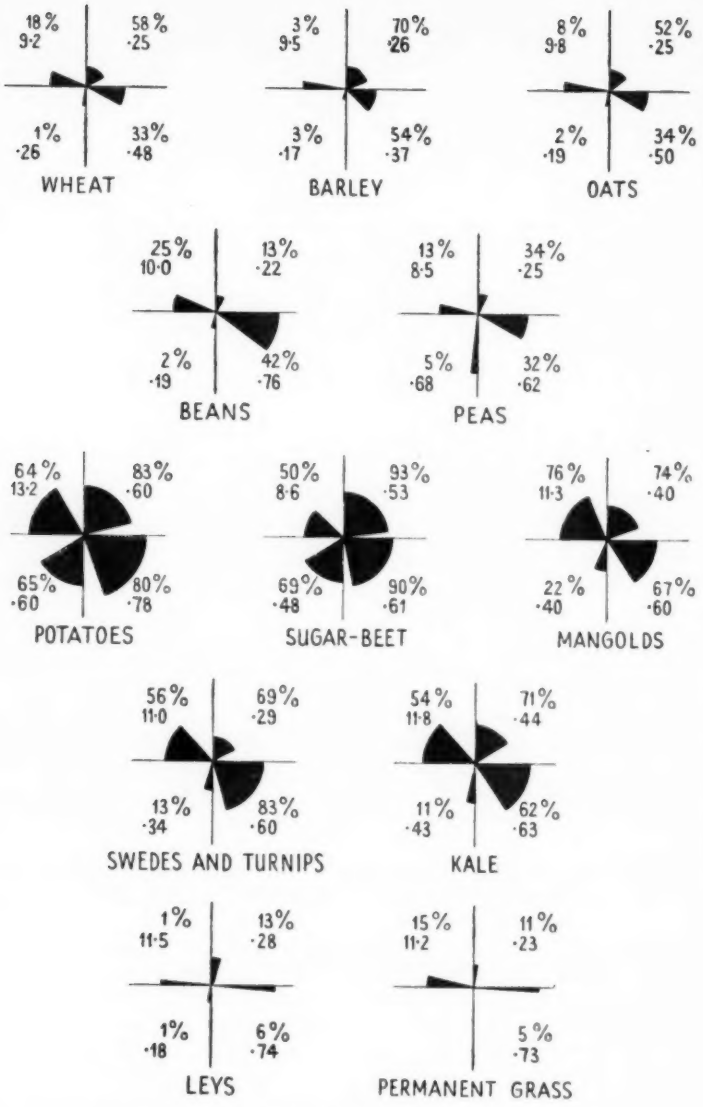

FIG. 4. Crop manuring diagram (all surveyed counties).

Key: F.Y.M. | N / K | P

The angles of the sectors represent the percentages of the acreage of each crop which receive F.Y.M., N, P, or K, an angle of 90° being equivalent to 100 per cent.; the radii represent the average actual dressings, the cross lines being equivalent to 1 cwt. N, P_2O_5, or K_2O, or 20 tons F.Y.M. Both these quantities are also shown in figures on the diagrams.

enabling farmers in these districts to dress a high proportion of the total acreage. On the other hand, in West Cambridge and West Bedford, where these drills are less common and rather less suitable, and in Hereford where phosphate is chiefly applied in the form of slag, individual dressings are often very high, with the result that few fields can be dressed.

The diagrams show similar differences in the manuring of root crops. Sugar-beet is the most uniformly manured crop. In all districts practically the whole of the sugar-beet acreage receives nitrogen and phosphate, and about two-thirds receive potash. The manuring of potatoes is more variable, both in the proportion of fields dressed in the different districts and in the amounts and proportions of the different fertilizer components. The three main potato districts, East Bedford, North Essex, and the Vale of York, show the most consistent use of fertilizers. The mixtures in these districts also approximate closely to the 1 : 1 : 1 ratio for N, P_2O_5 and K_2O. In the course of the last few decades there has been a gradual change in the main potato-growing districts from a predominantly phosphate manuring for potatoes to this more balanced mixture. Outside these districts (e.g. in the Pennines, Gloucester, Hereford, and Somerset) a much higher proportion of phosphate is still used, and fertilizers are in general used much less consistently; less than half the potatoes receive potash, and the average rates are very low. The principal mangold-growing districts, East Norfolk and the Vale of York, make adequate use of nitrogen and phosphate, but outside these districts a considerable portion of the mangold acreage receives phosphate alone or no fertilizer. The principal swede-growing districts use phosphate fairly consistently, but the use of nitrogen is much less consistent and the dressings are small.

Fig. 4 shows that beans and peas are frequently grown without fertilizer or farmyard manure. The use of farmyard manure on beans appears to be particularly important in view of their high potash requirements. Kale is manured very similarly to mangolds. There seems to be no doubt that heavier dressings of nitrogen could be used with advantage on this crop.

Somewhat over 10 per cent. of both the temporary and permanent grass fields receive nitrogenous dressings at an average rate of about 0·25 cwt. N, and about 5 per cent. receive phosphate (usually slag) at about 0·75 cwt. P_2O_5.

Relation between the use of farmyard manure and fertilizers.—As already mentioned, the use of farmyard manure does not influence appreciably the amount or type of fertilizers used. Differences in the dressings of nitrogen, phosphate, and potash with and without farmyard manure are shown in Table 2. The averages set out in this table are calculated so as to eliminate the effect of variation in the amounts of fertilizers applied in the different districts.

From Table 2 it will be seen that although the amounts of fertilizer used when farmyard manure is applied are in general slightly less than those when farmyard manure is not applied, the average differences are in all cases small. (A few districts, notably East Norfolk, show differences

decidedly larger than the average.) In view of the now established fact that crops respond equally well to inorganic nitrogen in the presence and absence of farmyard manure, but that the responses to phosphate and potash are substantially reduced by farmyard manure, it is clear that equally satisfactory manuring with and without farmyard manure will

TABLE 2. *Use of Fertilizers with and without Farmyard Manure*

(Dressings in cwt. per acre of N, P_2O_5 and K_2O on old arable land)

		N	P_2O_5	K_2O
Wheat . .	No F.Y.M.	0·17	0·16	0·00
	F.Y.M.	0·12	0·12	0·00
Potatoes . .	No F.Y.M.	0·47	0·57	0·43
	F.Y.M.	0·49	0·57	0·35
Sugar-beet . .	No F.Y.M.	0·49	0·56	0·33
	F.Y.M.	0·46	0·50	0·30
Mangolds . .	No F.Y.M.	0·44	0·42	0·16
	F.Y.M.	0·30	0·40	0·07
Swedes . .	No F.Y.M.	0·24	0·57	0·07
	F.Y.M.	0·21	0·49	0·02

be obtained only when farmers realise the need for using mixtures with different proportions of N, P, and K for the same crop in the two cases.

Treatment of newly ploughed-out land.—It has already been pointed out that farmers manure their old and new arable land very similarly. The real requirements, particularly in respect of lime and phosphate, are very different.

The distribution of seriously acid land in the three provinces given by soil samples taken in the course of the survey is shown in Fig. 6, which gives the proportion of old and new arable and grassland with pH 5·5 or less. At this level the range of cropping must be so restricted as to prevent any satisfactory crop rotation; such land is therefore in urgent need of liming. The map shows that although there is relatively little old arable land which is seriously acid, only the naturally calcareous districts (Cambridge, the Wiltshire downs, the Cotswolds, and the Yorkshire Wolds) had no new arable land below pH 5·5. In most of the surveyed counties 5 to 15 per cent. is very acid; the proportion is as high as one-quarter in Hereford and the Vale of York, and one half in the Pennine district of Yorkshire.

The estimated proportions of old and new arable and grassland limed in the four-year period 1939–42 are given in Fig. 7; in almost all districts more lime has been applied to old than to new arable land.

From these two figures we may conclude that most farmers have learnt by experience to maintain the lime status of their old arable land at a reasonably high level, but that only a small part of the grassland has in the past received lime sufficiently often to balance losses by grazing, haying, and leaching, and in consequence much of it was deficient in lime at the time of ploughing out. Subsequent liming has not been sufficient

FIG. 6. Acidity. (Percentage of old and new arable and grass fields with pH 5·5 or below.)

FIG. 7. Use of lime. (Percentage of old and new arable and grass acreage limed in 1939–42.)

to raise its lime-status to a satisfactory level, and there is no doubt that farmers have generally been unaware of the greater acidity of much of this land.

The situation with regard to phosphate is very similar. The soil analyses confirm that the newly ploughed-out land is markedly more deficient than the old arable land, yet in most districts, as is shown in

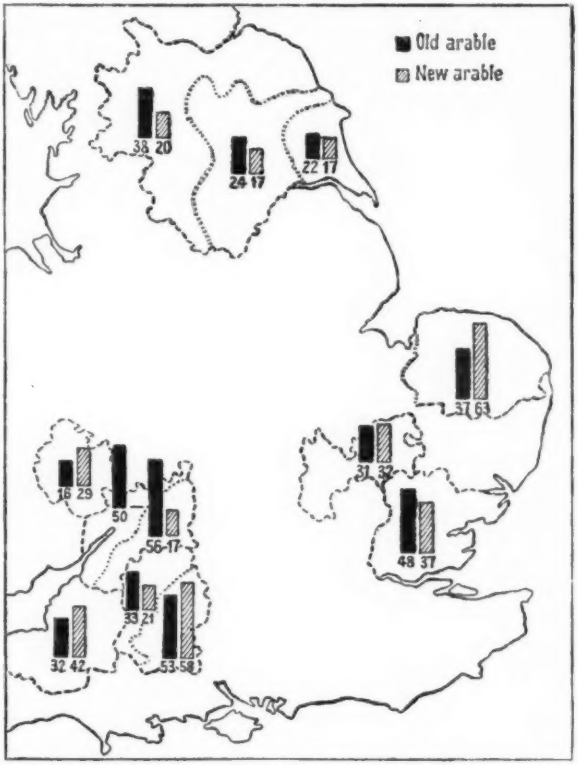

FIG. 8. Use of phosphate on new arable land. (Percentage of fields newly ploughed up for cereals and of old arable fields growing cereals which received phosphate in 1941–2.)

Fig. 8, less than one field in three of those ploughed up for cereals in 1942 received phosphate, the proportion being often somewhat less than for cereals grown on old arable land.

In some counties the County War Agricultural Executive Committees themselves, in their allocations to farmers in the 1943 scheme, did not take account of the different needs of old and new arable land, and allocated the whole of their phosphate supplies at a flat rate per arable or tillage acre. The survey in fact supplied important evidence for the change-over to the national scheme of 1943–4.

It may be noted here that in some counties (e.g. Gloucester, Wiltshire, and part of the West Riding of Yorkshire) half the root crops grown on new arable land received neither phosphate nor farmyard manure. The survey suggests that, generally speaking, root crops are grown only on new arable land by farmers with little or no old arable land: these farmers have little experience of arable farming or the proper use of fertilizers.

Salt.—Of the counties covered by the survey, only Norfolk and part of Yorkshire used any considerable quantity of salt. In Norfolk it was used on about 30,000 acres, chiefly on the lighter soils of western Norfolk; the greater part was given to sugar-beet and mangolds, but some was also applied to barley, swedes, and kale. The dressing was usually 3 to 5 cwt. per acre, but up to 10 cwt. was used occasionally. In Yorkshire salt was used on about 25,000 acres, chiefly in the Vale of York and the Wolds; it was applied to cereals as often as to roots and fodder crops, at rates of from 2 to 4 cwt. per acre. Its use was not restricted to sugar-beet and mangolds among the roots, or to barley among the cereals; indeed in the West Riding two of the sampled fields of potatoes were given salt!

No records were obtained of the use of salt in any of the western counties (except for a few fields of roots in Somerset) and very few in the eastern counties other than Norfolk. There appears to be considerable scope for its wider use on sugar-beet and mangolds. The low values obtained for soil potash in many of the western counties indicate that salt would probably prove of special value on these soils.

Conclusions

The results summarized above show that, generally speaking, districts which have always depended mainly on arable cropping use adequate amounts of fertilizers, and make satisfactory differentiation between the needs of different crops. Even in these districts, however, the special needs of newly ploughed-out grassland have not been fully recognized, and crops tend to be manured without regard to the land on which they are grown.

Farmers in the dairy and cattle-rearing districts of the west of England and Yorkshire, who before the war had had little experience of arable farming, are much less 'fertilizer-conscious' than farmers in the eastern arable counties, and make insufficient use of fertilizers, even on old arable land. For example, the manuring of root crops is frequently ill balanced and inadequate in the western counties; although very large supplies of farmyard manure are available, almost one-third of the root acreage received none, and many fields received no phosphate or no nitrogen. Even within the chief arable districts there were many farms mainly in grass before the war (e.g. in West Bedford and South Essex) which make less effective use of fertilizers than their neighbours with greater experience of arable farming.

As a consequence, the use of lime and phosphate on new arable land has been quite inadequate over most of the surveyed area. The survey has confirmed (what has already been frequently emphasized) that new arable land is generally both much more acid and much more deficient

in phosphate than old arable, but it is apparent that except in one or two districts this land has received less lime and less phosphate in recent years than has the old arable land.

It is, therefore, clear that considerably greater efforts are required to bring home to farmers the real differences in the needs of old arable land and newly ploughed-out poor grassland. There has been so much talk in the past about the 'stored-up fertility' of old grassland, that farmers, in so far as they recognize any difference in this land from their old arable land, regard it as less in need of fertilizers. There is certainly no general recognition of the fact that, whilst such land may be rich in organic matter and in available nitrogen, it is likely to be specially deficient in lime and phosphate.

The failure to recognize the function of farmyard manure as a source of phosphate, and more particularly potash, is also striking. The survey shows that farmers require encouragement to use mixtures with a lower proportion of phosphate and potash where farmyard manure is also given.

The failure to distinguish clearly between the different action of the various plant nutrients has also led to an inadequate use of nitrogen on cereals grown after roots, presumably owing to the belief that the heavy manuring of the roots will have led to sufficient stored-up fertility. Certainly in those cases where only inorganic nitrogen has been used to manure the root crop, there is every reason to give a reasonable nitrogenous dressing to the following corn. There are also wide differences from farm to farm in the use of nitrogen on cereals, and it is clear that some farmers, at least, could profitably make greater use of this fertilizer. Only half the acreage of cereals in the surveyed provinces actually received nitrogen, and it is unlikely that a higher proportion receives nitrogen in the country as a whole.

The shortage of potash is undoubtedly serious but, until considerably larger supplies become available, there is little that can be done other than to encourage the wider use of farmyard manure on crops having high potash requirements, reduction or omission of the potash dressing when farmyard manure is also given, prevention of waste in making farmyard manure, and the greater utilization of liquid manure. Where the acreage of priority crops and the allocation for soil deficiency are low, a considerable decline in the soil potash must be taking place. Soil analyses have shown that in the western counties a high proportion of the soils are already low in potash. Thus in the Cotswolds in 1942 less than 0·01 cwt. K_2O was used per acre of arable land, although half the soils have only 0·006 per cent. citric sol. K_2O or less.

Very little salt was used except on the lighter soils of Norfolk and the Vale of York, where it was used mainly, but not exclusively, on sugar-beet and mangolds. There is every reason to encourage the use of this fertilizer in other districts, and especially in the western counties, where it is likely to be of special value in view of the low potash status of much of the land.

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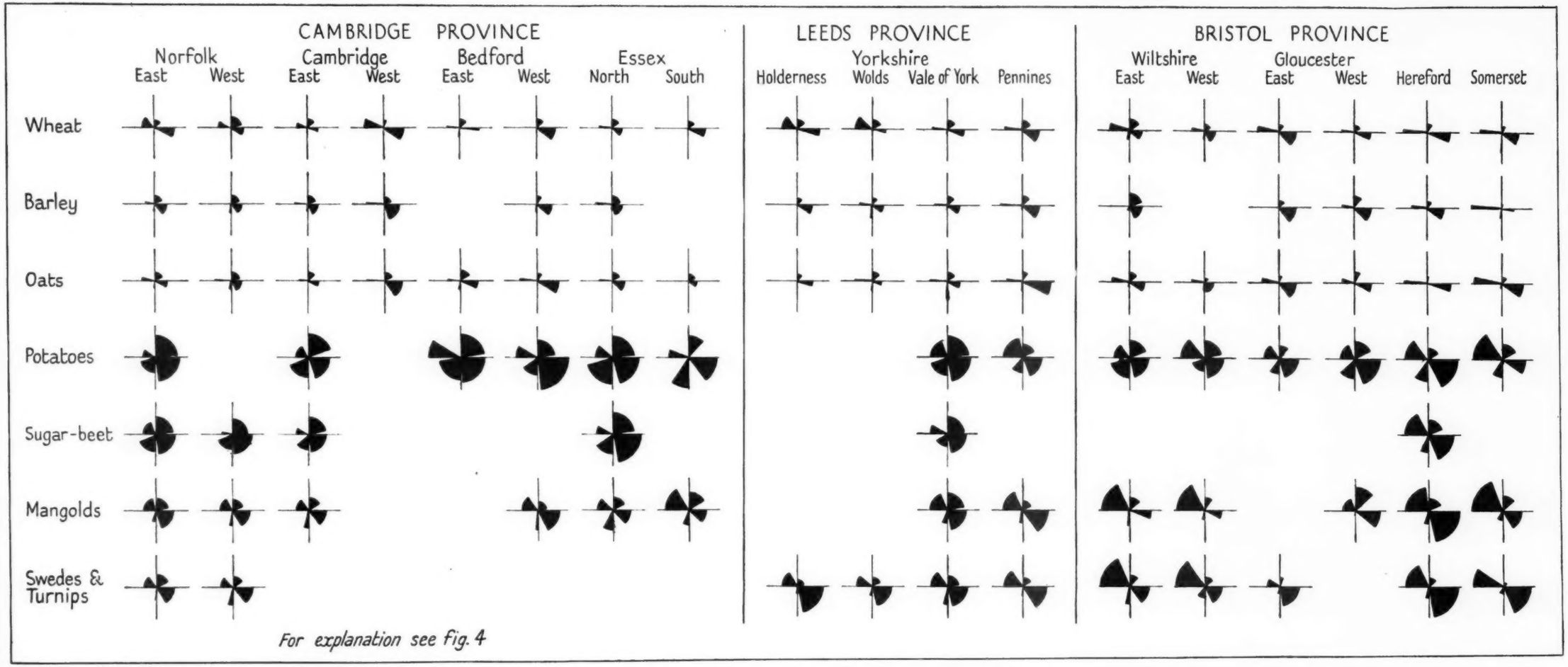

FIG. 5. Crop manuring diagram for counties and districts (*v.* pp. 169–71)

STUDIES IN THE YIELD OF TEA: PART V. FURTHER EXPERIMENTS ON MANURIAL RESPONSE WITH SPECIAL REFERENCE TO NITROGEN

T. EDEN

(Tea Research Institute of Ceylon)

In 1930 the Tea Research Institute of Ceylon started field experiments of factorial design to investigate the effects of manuring and cultivation on tea. The earliest of these experiments was reported in this journal at the end of the first complete 3-year pruning cycle [1]. Thereafter in the light of experience, the scope of this experiment was widened, and data for four complete cycles (12 years) are now available. The present paper deals mainly with responses to nitrogen, which have proved themselves to be of most interest, but for sake of completeness, responses to other nutrients are also summarized.

Yields of Plucked Tea

Except where specifically stated otherwise, all yields are in terms of dry matter.

Potash effects.—The earlier paper presented data which failed to show any significant response from potash manuring. As a whole, the 12-year period maintains this finding. Table 1 gives the yields per acre by pruning cycles with the appropriate criteria of significance. None of the responses is significant at the 5 per cent. level. Table 2 gives data for the last year of the last cycle in which a response emerges for the first time with a significance at nearly the 1 per cent. level. The year in question is a year of high yield, by reason of cumulative effects. It has in consequence a relatively low error. It remains to be seen whether in subsequent cycles this effect can be confirmed in the earlier and lower yielding periods of recovery from pruning.

TABLE 1. *Effect of Potash (muriate) (lb. per acre dry weight of tea)*

	1930–3 1st cycle	*1934–7 2nd cycle*	*1937–40 3rd cycle*	*1940–3 4th cycle*
K_0* . . .	2,142	1,853	1,609	2,321
K_{20} . . .	2,094	1,829	1,638	2,371
K_{40} . . .	2,148	1,833	1,648	2,438
Sig. diff. *P* 0·05 .	113	109	98	134

* The suffix in all tables indicates lb. of nutrient per acre applied annually in terms of K_2O, or P_2O_5, or N.

TABLE 2. *Potash Response, 3rd Year of 4th Cycle (lb. per acre dry weight)*

K_0 . . .	1,052	Variance Ratio 5·33
K_{20} . . .	1,104	*P* 0·05 significance 3·32
K_{40} . . .	1,170	*P* 0·01 ,, 5·39

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Phosphoric acid effects.—In the second and subsequent cycles advantage was taken of Yates's researches into orthogonality [2], and the phosphoric acid treatment was made variable. In place of a uniform application of 30 lb. per acre P_2O_5, nil, 30, and 60 lb. treatments were orthogonally superimposed on the existing nitrogen and potash variables. Main effects and first-order interactions of N × P and N × K were unconfounded. Two degrees of freedom of P × K were confounded with blocks. Table 3 gives the yields.

TABLE 3. *Effect of Phosphoric Acid (Superphosphate) (lb. per acre dry weight)*

	2nd cycle	*3rd cycle*	*4th cycle*
P_0	1,753	1,519	2,187
P_{30}	1,891	1,677	2,453
P_{60}	1,871	1,699	2,490
Sig. diff. *P* 0·05	109	98	134
,, *P* 0·01	146	132	180

From these results, phosphoric acid appears to be as effective at the lower as at the higher levels. When the yields for the two doses are amalgamated and compared with that from the no-phosphoric-acid treatment, the accuracy of the comparison is enhanced to a degree that gives significance at the *P* 0·001 level in the third and fourth cycles. In the several years of the pruning cycle, the average responses to phosphatic manuring are: 1st year 28 lb.; 2nd year 81 lb.; 3rd year 90 lb. per acre.

On this soil the lower level of phosphatic manuring is able to supply almost, if not all, the phosphoric acid needed by the crop. The marked curvature of this phosphoric acid response is typical of many tropical red-earth soils.

TABLE 4. *Nitrogen Response for Four Pruning Cycles (lb. per acre dry weight)*

A

	1st cycle	*2nd cycle*
N_0	1,962	1,641
N_{20}	2,130	1,829
N_{40}	2,294	2,045
Sig. diff. *P* 0·05	113	109
,, *P* 0·01	152	146

B

	3rd cycle	*4th cycle*
N_{40}	1,483	2,080
N_{60}	1,613	2,373
N_{80}	1,799	2,678
Sig. diff. *P* 0·05	98	134
,, *P* 0·01	132	180

Nitrogen response.—Throughout the four pruning cycles the main feature of the response to nitrogen has been its regularity. Table 4 gives the yields for the individual cycles.

At the beginning of the third cycle a change was made in the manuring programme and all nitrogen plots were stepped up by 40 N per acre.

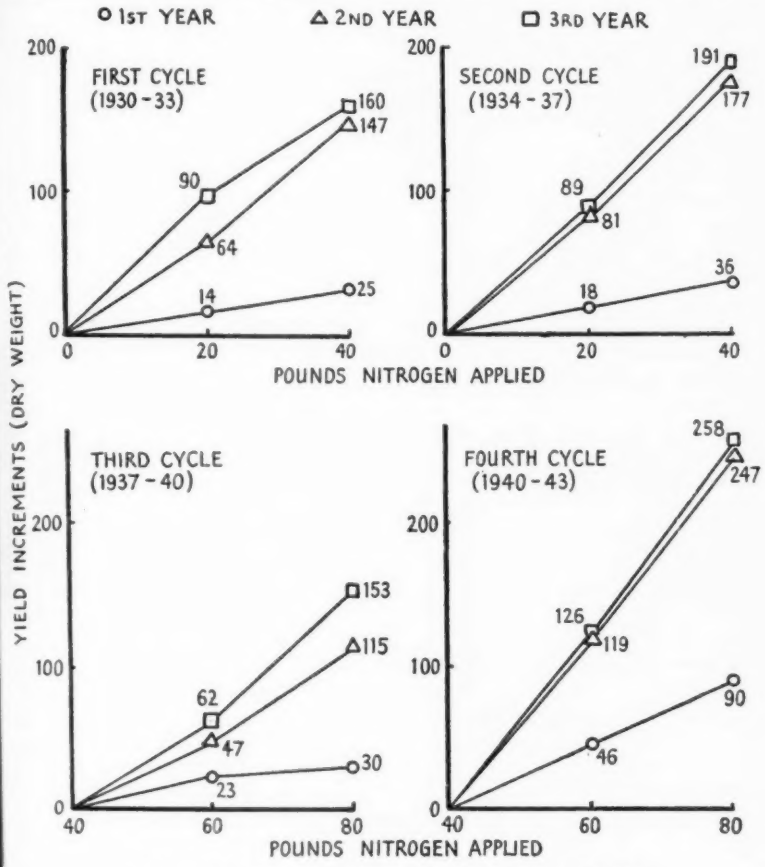

FIG. 1. Effect of nitrogen on yield increments of flush.

This was deemed advisable for two reasons. Firstly, it was desired to explore higher levels of nitrogen application, and secondly, it was thought inadvisable to allow a perennial crop to deteriorate indefinitely on account of acute nitrogen starvation, which would eventually vitiate the usefulness of the data as a basis for practical agricultural advice. The consequences of this change will be seen later.

The examination of the yields in greater detail year by year confirms the constancy of the nitrogen effect and brings out further points which

are displayed in Fig. 1. In this diagram the datum line is taken as the lowest yield for each particular year, so that the values plotted against the nitrogen applications are the increments of yield on each occasion.

The linear response of nitrogen in increasing dosage is prominently shown in all years. When the response is calculated as a linear regression for purposes of an analysis of variance, it is found that the sum of squares of deviations appropriate to the regression never falls below 98·8 per cent. of the total nitrogen sums of squares, and in four instances (2nd cycle, first year; and 4th cycle, all years) the value exceeded 99.

Inspection of these regressions shows that they follow a regular pattern throughout: the response to nitrogen in the first year is markedly inferior to that in later years. Further, although the third cycle does not (for reasons detailed later) conform so nearly as the rest, the regressions in the third and fourth years are very nearly equal.

The different behaviour in the first year is connected with the development of the bush after pruning. At the elevation of the Tea Research Institute (4,600 ft.) it takes some $4\frac{1}{2}$ to 6 months before the bushes are again in bearing. For about two-thirds of this time the bushes are allowed to grow unchecked, but thereafter on three occasions the shoots are broken back or 'tipped' to a level of 4 in. above the pruning cut at the centre of the bush, in order to establish a level surface or plucking table from which manufacturable flush-shoots will subsequently be removed. In consequence of these operations the first year from pruning provides a smaller number of harvests than the subsequent years—on an average 25 instead of 40. Even when tipping-growth is accounted for, the utilization of nitrogen in the first year remains poor. This is brought out by plotting responses in crop per lb. of N applied, as in Fig. 2 (*a*). The circles represent data for ordinary flush: the squares refer to combined tippings and flush in the first year. These results indicate that a factor is operative after each pruning which reduces the efficiency of the bush as a user of manurial nitrogen.

No detailed physiological work has been done on the effect of tea-bearing on the uptake, transport, and elaboration of nitrogen, but the results of these experiments suggest that the uptake must be rapid. The main support for this hypothesis comes from the fact that if nitrogen were absorbed piecemeal, the vagaries of weather would have very distinct effects on the efficiency of that uptake. Consequently, the maintenance of the observed linearity of response (Fig. 1) from year to year would be jeopardized. If, on the other hand, the bulk of the nitrogen is quickly absorbed and stored for use in promoting growth at favourable seasons, the observed results are understandable. Accepting tentatively this explanation, the low ratio of crop to nitrogen applied in the first year might indicate a failure of the plant to make use of the nitrogen in the considerable quantities applied immediately after pruning.

A full explanation of this observed inefficiency must await detailed physiological inquiry, but pointers exist in support of a probable explanation.

The effective feeding-root range in tea is not very great. The writer found previously [3] that 70 per cent. of the small feeding-roots are con-

tained in the first foot below ground, which is regularly disturbed by cultivation, whilst in the region between 21 and 24 in. only 4 per cent. by weight of the total in the first 2 feet were recoverable by a sampling procedure. Losses of nitrogen to lower depths may well take place in substantial amounts during the post-pruning period before the bush has built up a canopy of foliage.

How effective the root-system is immediately after pruning is not known. This may affect the point at issue. Rogers [4] and Rogers and Vyvyan [5] found that top growth of apples was closely associated with root-growth, and that the active life of a feeding-root ended within a short time of lignification setting in. This suggests that immediately after pruning active root-growth may be delayed, and that the proportion of new root capable of absorption may fall, whilst that of lignified and hence inactive roots may rise. Maskell and Mason [6], in their studies of nitrogen transport in cotton, conclude that mineral nitrogen after absorption by the roots is transported to the leaves, is there elaborated to amino-acids, and is then exported to the growing regions of the plant. From these considerations it appears likely that in tea, failure to use nitrogen immediately after pruning is linked either with failure to absorb it or with failure to elaborate it owing to the completely leafless condition of a clean pruned bush. These hypothetical explanations can be put to the test in some degree by studying the effect of delaying the application of manure to pruned tea.

In the third and fourth cycles this was effected by dividing the nitrogen plots into three groups, one of which continued to receive an application immediately after pruning; one received its supply 3 months later, and the third 6 months after pruning, when the canopy was past the tipping stage. The effect of staggering these applications (in the first year only) was observed on the tipping yields and on the subsequent normal flush. The results for tippings are given in Table 5. It is worth while to emphasize again that at this time the third group had received no manure at all since pruning.

TABLE 5. *Yield of Tippings as affected by Delayed Manuring of Clean Pruned Tea* (*lb. dry weight per acre*)

Cycle	*Time of manuring—Months after pruning*			*Sig. diff.* P 0·05
	0	3	6	
3rd	243	225	237	22
4th	281	272	282	30

Such small differences as are observable all fall within those attributable to random error. As far as recovery from pruning is concerned, manuring at the time of pruning or even 3 months later appears to be quite ineffective.

A supplementary experiment carried out with tea differently pruned provides further evidence. In this experiment a fringe of leaf-bearing branches was left round the perimeter of every bush. This fringe was intended primarily to safeguard the bush from the possible effects of

carbohydrate depletion of the roots, which frequently occurs at lower elevations (below 3,000 ft.). New growth took place both from the clean wood and from the branches still bearing leaves (locally and erroneously called 'lungs'). These two kinds were weighed separately. No significant difference between the various treatments was discernible at tipping time between 4 and 5½ months after pruning. The yields and times of application of manure are given in Table 6.

TABLE 6. *Yield of Tippings as affected by Delayed Manuring of 'Rim Lung' Pruned Tea (lb. per plot green weight)*

	Times of Application				*Sig. diff.*
	Nil	*At pruning*	*After 2 months*	*After 4 months*	*P* 0·05
Tippings	43·3	44·5	42·0	42·4	3·5
New 'lung' growth	44·7	48·7	44·9	46·6	9·4

The subsequent history of the main experiment is shown in Table 7. At progressive stages in the cycles the cumulative yields for the groups of plots with delayed applications are tabulated as offsets from the corresponding yields of plots manured at pruning time.

TABLE 7. *Gain in Crop due to Delayed Manuring (cumulative dry-matter yields per acre in lb.)*

Third cycle 1937–40

	Delayed 3 months	*Delayed 6 months*
At 25th pluck	28	37
,, 50th ,,	46	76
,, 75th ,,	43	90
,, 100th ,,	46	107

Fourth cycle, 1940–3

	Delayed 3 months	*Delayed 6 months*
At 25th pluck	35	52
,, 50th ,,	7	94
,, 75th ,,	−17	107
,, 100th ,,	−42	102

The results in the two cycles are not homogeneous. In the third cycle a 3-month delay gave an advantage which gradually wore off, the gain becoming stabilized. The 6-month delay showed an advantage which persisted much longer, actually well into the third year, despite the fact that all plots received further manuring 12 and 24 months after pruning. It is difficult to account for this persistent effect unless it be that the early advantage in growth makes the bush better able to use subsequent applications.

In the fourth cycle the 6-month delay gives results comparable with those in the previous cycle, but the 3-month delay, after giving positive

values at first, subsequently lapses into negative values. Examination of the records has failed to elucidate any reason for this, or to disclose any error of procedure in the field that would account for it. The balance of evidence, taking into account the statistical significance of delayed manuring as a whole, is in favour of delaying the manuring until the bush has grown an efficient canopy of leaves.

In addition to variation in the efficiency of nitrogen during the course of the pruning cycle, Fig. 2*a* shows that there has in general been a uniform increase in efficiency from the earliest date if the third pruning

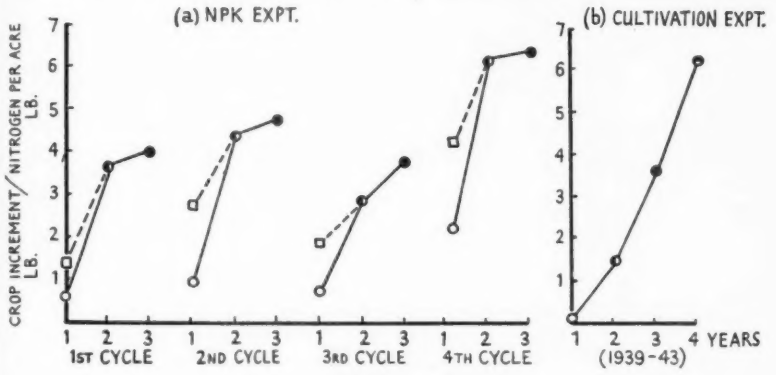

FIG. 2. Efficiency of nitrogen.

cycle is omitted. The third cycle is anomalous because owing to drought periods early in 1938 and 1939 it was checked in early growth and gave a low cycle-yield. The increase in efficiency is demonstrably the same whether we consider the points of the first-, second-, and third-year data or the points representing tippings and flush. Considering comparable periods in the cycle, the increment in the ratio lb. crop to lb. of nitrogen applied, over the 12-year period, is for total first-year crop 2·8, for the second year 2·5, and for the third 2·4. These increments appear to be unaffected by the change in level of the manuring half-way through the experimental period. It seems clear that this tea is working up to a maximum value in efficiency of nitrogen utilization dependent on cultural methods, spacing, and other comparative factors.

Figure 2*b* gives a corresponding picture, for one 4-year cycle only, of the nitrogen efficiency on the cultivation trial previously cited. The maximum value reached (6·2) is similar to that in Fig. 2*a*, and both these values are in agreement with that quoted by Carpenter (6·4) under Assam conditions [7]. What distinguishes the two sets of data are the different patterns of the efficiency curves and also of those of actual yield (Fig. 3). Experience shows that the form of these efficiency- and yield-curves remains true to type from cycle to cycle. Here one can do no more than note the diversity in these response-patterns without dogmatizing on their fundamental cause. The tea to which Fig. 2*b* relates is much younger than that of the manurial experiment Fig. 2*a*, and the type of

tea (jât) is different. Further inquiry into the influence of age and jât on manurial efficiency is suggested by these data.

Production of Foliage Leaf and Wood

The effect of manuring is reflected in the growth of the bush as a whole. In the main, the effects are of the same kind as those found in the

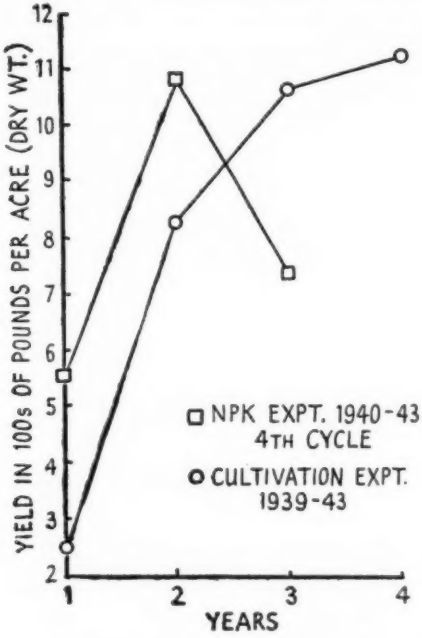

FIG. 3. Yield-patterns of pruning cycles for two experiments (cf. Fig. 2).

flush yields. The sampling problem is formidable and errors are large. The technique followed is described in Part III of this series. By foliage-leaf is meant the mature leaf that remains unplucked and is removed at pruning time. It is stripped from the prunings and weighed. The residue of the prunings is weighed as wood.

Potash and Phosphoric Acid Effects (*Table 8*)

Potash.—As with the flush, potash shows no effect on leaf and none on wood till in the fourth cycle an entirely anomalous result appears. At the K_{20} level a yield of wood is shown which is significantly different from the K_0. The K_{40} level is not significantly different from either of the other treatments. Subsequent cycles will show whether, as seems likely, this result, which is very difficult of interpretation, is merely the product of the 1 in a 100 probability which has to be risked in any experiment [8].

Phosphoric acid.—The influence of phosphoric acid begins to assert itself after one cycle in both foliage and wood.

Effect of Nitrogen

In essentials the nitrogen responses for foliage and wood closely follow those displayed by flush yields. The straight-line regression of yield on nitrogen is equally striking except in the first cycle, where small yields and a technique new to the labour force militated against refinements in accuracy which later, in the light of experience, received further attention. But whereas in flush yields there was evidence of an increase in response per lb. of nitrogen given as the pruning cycles succeeded one another, there is no such tendency in these data either for foliage or for wood (Fig. 4).

TABLE 8. *Effect of Potash and Phosphate on Yield of Air-dried Foliage-leaf and Pruned Wood (lb. per acre: 3,000 bushes per acre)*

	Foliage-leaf				*Pruned wood*			
	1st cycle	*2nd cycle*	*3rd cycle*	*4th cycle*	*1st cycle*	*2nd cycle*	*3rd cycle*	*4th cycle*
K_0	1,550	2,300	2,670	2,464	2,160	5,900	6,300	7,666
K_{20}	1,670	2,410	2,680	2,673	2,280	6,100	6,300	8,908
K_{40}	1,650	2,340	2,700	2,569	2,300	5,990	6,430	8,298
Sig. diff.* P 0·05	183	195	219	242	350	525	570	749
P_0	..	2,270	2,530	2,449	..	6,000	5,810	7,590
P_{30}	..	2,370	2,690	2,543	..	5,880	6,510	8,395
P_{60}	..	2,410	2,840	2,714	..	6,110	6,710	8,888

* The significant differences are common to both sets. The P 0·01 value for the 4th cycle is 1008.

The most noticeable difference between the growth of flush on the one hand and foliage-leaf and wood on the other lies in the frequent removal and renewal of the former, in comparison with the permanence of the latter. The similarity of the regressions for foliage-leaf and wood suggests that there is an efficiency limit for the maturer tissues which operates under the particular standardized conditions of culture practised in this experiment. For other conditions a different limit might be expected. The limiting factor of space suggests itself.

The data here considered relate to four arbitrary but distinguishable types of growth, viz. (1) the young primary shoots produced after pruning (tippings), (2) the flush harvested every 9 days, (3) the permanent foliage, and (4) the growth of new wood. It has sometimes been supposed that manuring can produce flush at the expense of the frame of the bush, but the need for development of a good frame is regarded as axiomatic in agricultural circles. It is hard to imagine any botanical support for the former contention, and it would seem that although varying systems of pruning and plucking may well alter the quantitative relationships between the various growth-categories, their fundamental correlation is a physiological necessity. That this is so is demonstrated

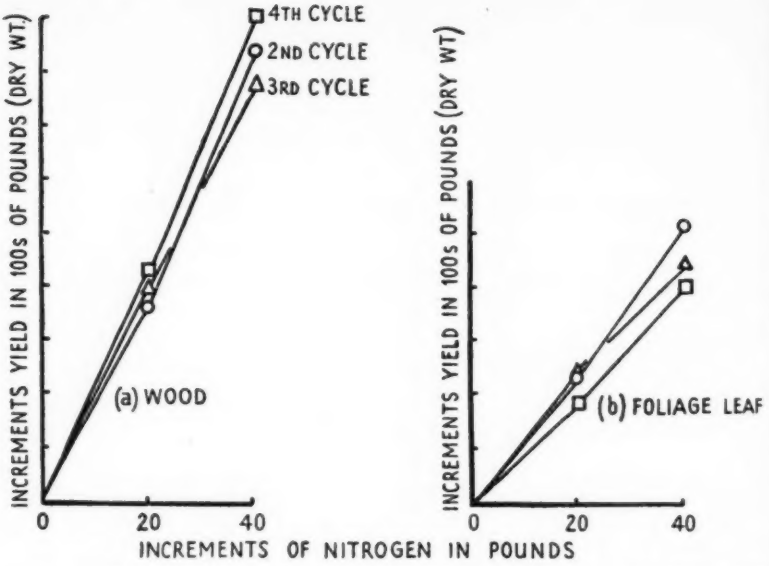

FIG. 4. Effect of nitrogen on increments of (*a*) pruned wood and (*b*) foliage-leaf.

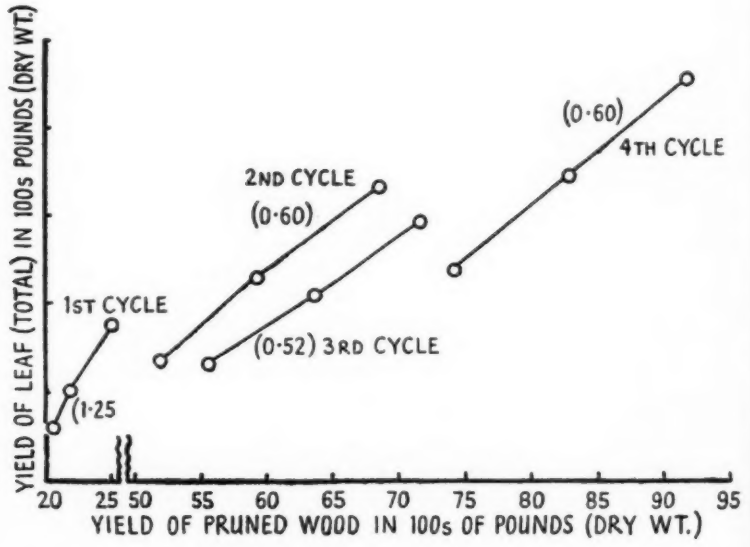

FIG. 5. Relationship between yields of leaf and wood.

by the data in Fig. 5. In this diagram the plotted points represent the mean yields of (*a*) wood, and (*b*) the total of the other three categories, tippings, flush, and foliage-leaf, at the three levels of nitrogenous manuring. From the data it is obvious that the increments of nitrogen give increments of leaf and wood that are strictly proportional. The correlations between flush and foliage-leaf (not shown here) are equally distinct.

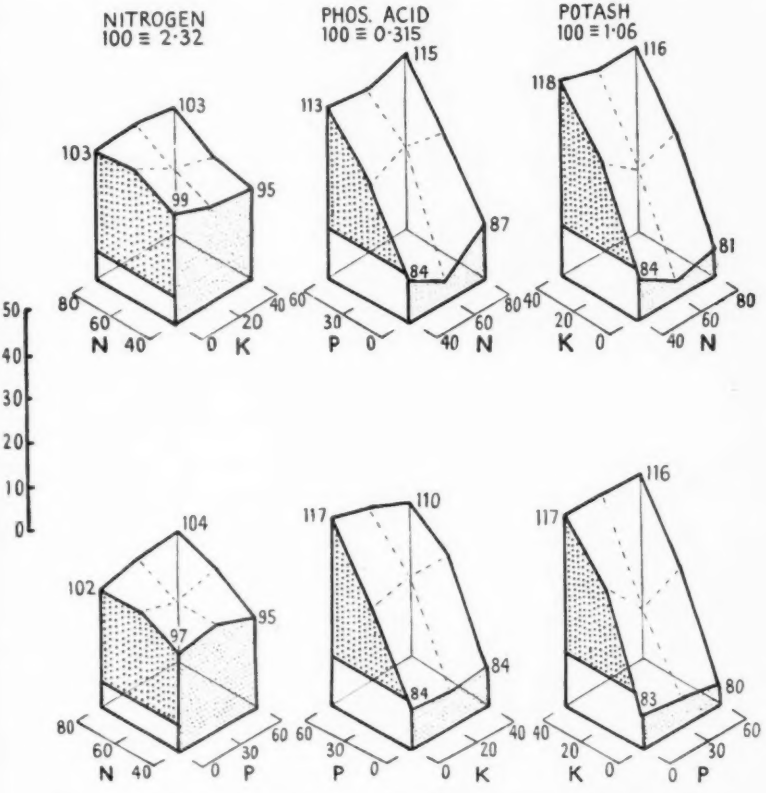

FIG. 6. Variation in foliage-leaf composition (per cent. of mean for each component respectively).

There is thus no support for the view that nitrogenous manuring *per se* stimulates differentially flush and frame-growth. Fig. 6 brings out a further point. In the last three cycles the advantage of previous experience in sampling technique together with higher yields contributed to higher accuracy. The results show a remarkably stable relationship between total leaf and wood. The regression coefficients in each instance are shown adjoining the regression line.

The Effect of Manures on the Composition of the Foliage-leaf

Manurial treatments have had a marked effect on the composition of the tissues of the tea plants under experiment. Inability to replenish stocks of reagents for analysis during war-time has prevented a survey of changes in wood composition, but the data for foliage-leaf are given for the third cycle, 1937–40. Fig. 6 plots the data in the form of isometric prisms. The heights represent the composition, in respect of a particular nutrient, as a percentage of the mean value. This percentage is plotted against the nine combinations of the three manurial doses for pairs of fertilizers. The surfaces of these prisms give the essential picture, and the prisms have accordingly been truncated arbitrarily at 75 per cent. to save space. The dimensions of the significant differences are shown by the unshaded bands at the base of the left-hand side of each prism.

It is evident that the nitrogen-content of the leaf is changed less by nitrogenous manuring than the potash-content is by potash manuring on the one hand, or than the phosphoric-acid content is by phosphatic manuring on the other. The exigencies of further growth may be expected to withdraw nitrogen from leaves when a critical but undefined concentration is attained, but as regards the other two nutrients something like luxury consumption is attained. This is of particular interest for potash, since, as has been shown, yield-effects from potash manuring are absent.

It is noticeable that for phosphate also the addition of manure promotes a change in leaf-composition even when there is no response in yield. Similar results have been shown to occur on grassland under phosphatic trials [9]. There are no interactions between the various manurial effects. In fact, the significant differences produced are confined to the action of a single nutrient on the composition of the leaf in respect of that nutrient. On an average, an extra 40 lb. of N has changed the N-composition of the leaf by only 6·7 per cent. The corresponding change in potash composition for a 40-lb. application of potash is 35·2 per cent., and in phosphoric-acid content 30·2 per cent. for a 30-lb. application.

Conclusions

The data here presented, covering 12 years of continuous manurial experiments, make possible a more complete understanding than hitherto of the influence of added nitrogen on the growth of the tea crop. A connected sequence of stages in the response of tea can be traced.

Within each pruning cycle the response increases with time, and though the pattern of that increase is not standard for different fields and different pruning cycles, it shows a tendency to approach a maximum at about 6·0–6·5 lb. of crop (dry matter) per lb. of nitrogen applied. In a previous paper (loc. cit.) the remarkable linear relationship between dose and crop was attributed to the special circumstances under which tea is grown, viz. that the whole of what is harvested as crop is the product of the vegetative growth of the plant. This is confirmed by the more extensive data now obtained. With crops that have specialized storage organs in the form of seed or roots other factors have a large part in

determining whether growth-response shall or shall not eventually be reflected in crop-response.

Despite the simplification in relationship between vegetative growth and crop, the nitrogen response in tea is poor when compared with temperate annual crops. The same fact was noted as regards nutrient recovery in the previous paper (loc. cit.). Crowther and Yates [10] have recently examined in great detail the average responses of European farm crops to standard amounts of fertilizers. Using their response curves, figures have been calculated which make a comparison between the present data and theirs possible, bearing in mind that the present results are derived from leached upland soils of the red-earth type overlying acidic parent rocks. All figures have been reduced to terms of dry matter. For European crops a variety of sources have been used for average dry-matter contents. These sources and their values are as follows:

	Per cent. dry matter
Cereals [11, 12]	83
Swedes [11, 13]	11
Mangolds [11, 13]	11
Potatoes [14]	22·5

Table 9 gives comparable yields for these crops and for tea for standard amounts of nitrogen and phosphoric acid.

TABLE 9. *Response in Dry Matter to 40 lb. N and 30 lb. Phosphoric Acid, respectively*

Crop	*Nitrogen response lb. per acre*	*Phosphoric-acid response lb. per acre*
Cereals	418	44
Swedes	665	198
Mangolds	933	126
Potatoes	583	101
Tea	258 (maximum)	113

The response of tea to phosphoric acid may be regarded as within the normal range. The corresponding figures for potash are not tabulated because the response is absent. Woodford and Cooper [15] have demonstrated a potash effect on young tea in Assam, but no such effect is visible in older tea in full production. The change in foliage-leaf composition when potash is increased indicates a luxury consumption for potash, but for yield purposes potash appears to have as yet but little significance.

Summary

(1) The results of four complete pruning cycles covering 12 years in a field experiment on tea are given. They describe the responses to N, P, and K at three levels factorially combined.

(2) Potash gives no consistent increase in yield; phosphate shows a moderate response to 30 lb. P_2O_5 per acre but no further distinguishable increase at 60 lb. per acre.

(3) The most striking effect is that of nitrogen, which gives proportional responses up to 80 lb. per acre. The efficiency of nitrogenous manuring increases as the bush grows larger in each pruning cycle and is noticeably low in the first year. The efficiency also increases from pruning cycle to pruning cycle, and a maximum figure of 6·4 lb. of crop (dry weight) per pound of nitrogen applied has been reached.

(4) The inefficiency of the nitrogen early in the first year of the cycle is associated with the plant's leafless condition during its recovery from pruning. Later application brings about some improvement.

(5) The responses in foliage-leaf and pruned wood were similar to those of flush. The correlation between leaf and wood-formation is high.

(6) Manurial treatments have produced a noticeable effect on the chemical composition of the foliage-leaf. Relatively the effect is more marked with potash and phosphate than with nitrogen. The changed-composition effect is confined to the nutrient which is applied. There are no interactions. Phosphate and potash produce compositional effects even when no yield effects are visible.

Acknowledgements.—No account of these experiments would be complete without recording my appreciation of the labours of my assistants in making the large number of routine determinations of yield and dry matter, some 65,000 in all, and the chemical analyses. I am indebted to Mr. M. Piyasena for the former and to Mr. E. N. Perera for the latter.

REFERENCES

1. T. Eden, Studies in the Yield of Tea: Pt. III. Empire J. Expt. Agric., 1935, **3**, 105–18.
2. F. Yates, The Principles of Orthogonality and Confounding in Replicated Experiments. J. Agric. Sci., 1933, **23**, 108–45.
3. T. Eden, Studies in the Yield of Tea: Pt. IV. Empire J. Expt. Agric., 1940, **8**, 269–79.
4. W. S. Rogers, Soil Factors in relation to Root Growth. Trans. 3rd Int. Congress Soil Sci. 1935, **1**, 249–53.
5. —— and M. C. Vyvyan, Rootstock and Soil Effect in Apple Roots and Stems. J. Pomology, 1934, **12**, 110–50.
6. E. J. Maskell and T. G. Mason, Studies on the Transport of Nitrogenous Substances in the Cotton Plant: Pt. I. Annals of Botany, 1929, **43**, 205–31.
7. P. H. Carpenter, The Application of Science to Modern Tea Culture. Empire. J. Expt. Agric., 1938, **6**, 1–10.
8. F. Yates, The Design and Analysis of Factorial Experiments. Imp. Bur. Soil Sci., 1937. Tech. Comm. 35.
9. Rothamsted Experimental Station Report for 1936, pp. 32–6.
10. E. M. Crowther and F. Yates, Fertilizer Policy in War Time: The Fertilizer Requirements of Arable Crops. Empire J. Expt. Agric., 1941, **9**, 77–97.
11. P. McConnell, Agricultural Notebook, 11th edit., Macdonald & Martin Ltd., 1930.
12. H. Hunter, Encyclopedia of Agriculture. Ballière, Tyndall & Cox, 1931.
13. J. H. Gilbert, Agricultural Investigations at Rothamsted, England, 1895. U.S. Dept. Agric. Bulletin No. 22.
14. L. H. Lampitt and N. Goldenberg, The Potato as Food: the Composition of the Potato. Chem. & Ind., 1940, **59**, 748–61.
15. F. K. Woodford and H. R. Cooper, A Factorial Experiment on the Manuring of Young Tea. Empire J. Expt. Agric., 1941, **9**, 12–22.

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OBSERVATIONS ON THE ROOT-SYSTEMS OF ROBUSTA COFFEE AND OTHER TROPICAL CROPS IN UGANDA

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WITH PLATE 10

Introduction and Methods of Sampling

ROBUSTA coffee (*Coffea canephora*) grows wild in many of the wetter forests of Uganda; it is frequent in moist hollows where the ground is waterlogged at some seasons, and it is seldom present in the drier forests on the tops of the hills. Examination of many wild trees has shown that their root-systems were largely confined to the upper layers of soil: the main lateral roots radiated near the surface of the ground and there was an abundance of fine feeding-roots in the superficial soil and in the thin layer of fallen leaves which covers the ground [1]. As the wild robusta coffee has so shallow a root-system, it seemed worth while to investigate the distribution of the roots of cultivated plants, for, if most of their roots were near the surface of the ground, this distribution would have an important bearing on the cultivation of the crop.

Nutman [2] has described the root-system of arabica coffee as shown when the soil was washed away by a jet of water; and he has also described the spatial distribution of the feeding-roots as it was shown by washing out cubic feet of soil at different depths below the surface and at different distances from the stem of the bush [3]. Neither of these methods was feasible for examining the roots of wild robusta coffee trees growing in the Uganda forests; a simpler method had to be used.

The most convenient way of estimating the vertical distribution of the coffee roots in the soil was found to be by taking soil cores with an auger, carrying the soil back to the laboratory in air-tight bags and, while it was still wet, picking out the roots with needles and forceps. The roots from each sample were then placed in dilute formalin until they could be dipped into gum and mounted end to end in lines on ruled paper; by measuring these lines it was possible to discover the length of root in each sample of soil. As Nutman has pointed out, it was obviously better to estimate the amounts of root by length than by weight, for the mass of fine absorbing roots was very light in comparison with the thicker, woody, main roots. An attempt was made to grade the roots in size according to their diameter, but it was found to be impracticable and therefore the results are given as the total length of roots, large and small, in each layer of soil.

The first batches of samples were taken with a 2-in. soil auger and were divided into the following depths: 0 to 3 in., 3 to 6 in., 6 to 12 in., and 12 to 18 in. Ten cores were taken at random in a group of trees and the samples from each depth were bulked. Later samples were taken with a Veihmeyer type of auger, graduated in centimetres, the samples being taken to depths of 0 to 8 cm., 8 to 16 cm., 16 to 32 cm., and 32 to 48 cm. This auger had a cross-section measuring 10 sq. cm. in area; it

was hammered into the soil by dropping the weight on the end, a count being made of the number of hits required to drive the auger to each depth; these numbers gave a measure of the compactness of the soil. The samples taken by this method were kept separate and the roots that they contained were mounted and measured separately; the distance of each core from the nearest tree also was measured, and an attempt was made to discover if there were any correlation between the amount of roots present, their depth in the soil, and the distance from the tree; no correlation, however, could be found and it seemed that, when the coffee had reached maturity, the distribution of roots over the surface of the plot was influenced by minor local variations in soil composition more than by distance from the trees.

In order that the results from samples taken with both augers may be compared, the results in each case have been expressed as the length of roots in a cubic centimetre of soil. Samples taken with the auger graduated in inches are marked with an asterisk, for they do not exactly correspond with those taken with the auger graduated in centimetres, for 3 in. is equal to 7·62 cm. and not to 8 cm.; the error due to this factor is reduced by the fact that the end of the Veihmeyer auger was slightly worn and the top samples were to a depth of rather less than 8 cm. Such adjustment will show that the figures in this paper can be regarded only as approximate, and useful for the purposes of comparison rather than for accurate measurement of the root-systems.

There were other sources of error. Nutman estimated that in his assessment of their length about 20 per cent. of the roots were ignored, and it seemed that a small amount, but less than 20 per cent., may have been overlooked in the observations recorded here. Furthermore, the samples represented a very small part of the total surface of the ground that was sampled; 10 cores, each having an area of 10 sq. cm., will give a total area of only 100 sq. cm.

It has not been feasible to employ a larger number of samples because of the excessive time that would have been needed to sort out the roots and to mount them, even with the aid of a number of African assistants; the samples used, which were of 10 cores, each with an area of 10 sq. cm. and penetrating to a depth of 48 cm., comprised 4,800 c.c. of soil and contained up to 4,000 cm. of roots. In spite of all these drawbacks, the differences in root-lengths at different soil depths and under different conditions were so striking as to seem worthy of record.

The Root-system of Robusta Coffee

The results obtained by the sampling of *Coffea canephora* roots in different places are recorded in Table 1.

Samples 1 and 2 were from places where wild *Coffea canephora* was dominant in the undergrowth of the Itwara forest in the west of Uganda. The profile of the soil was:

0 to 2 cm.: litter of fallen leaves.
2 to 8 cm.: dark mould, rich in decomposing leaves and roots.
8 to 16 cm.: brown friable loam.
16 to 48 cm.: red clay.

In sorting roots from these samples all that were obviously not those of *Coffea canephora* were discarded, but it is probable that some of the roots which were retained were those of other plants.

Care was taken that the other samples were from situations where there could be no admixture with roots of other species resembling those of coffee; sample 5 contained roots of *Centrosema pubescens*, sample 6 those of a mixture of grasses, and sample 9 those of *Digitaria scalarum*, but all of these roots were easily distinguished from those of coffee and were picked out.

The soils from which samples 3 to 9 were taken were typical of much of the more fertile parts of Uganda, having about 16 to 24 cm. of dark loam, slightly acid in reaction, overlying a more acid red clay or clay loam. Sampling was not carried out below 48 cm. because it was difficult to knock in and to withdraw the auger if it penetrated below this depth; the figures in Table 3 show how compact the soil even at depths of 32 to 48 cm. might be. When the soil was so compact it would be expected that there would be little growth of roots in it; excavation to greater depths showed that there were seldom more than a very few roots of robusta coffee at depths below 48 cm. in Uganda—the few which had penetrated deeper usually had followed down the traces of dead roots of other plants. Therefore, though it cannot be claimed that sampling to a depth of 48 cm. revealed the whole root-system of robusta coffee in Uganda, yet there is little doubt that it did comprise at least 95 per cent. of the total length of roots.

TABLE 1. *Distribution of Robusta Coffee Roots at Different Localities and under Different Treatments*

	Plot sampled	Average length (cm.) of root per c.c. of soil at depths of:				
		0–8 cm.	*8–16 cm.*	*16–32 cm.*	*32–48 cm.*	*0–48 cm.*
1.* *Coffea canephora*.	Itwara Forest, Toro. Wild trees .	1·82	0·47	0·15	0·07	0·46
2. ,, ,,	,, ,, ,, ,, .	1·64	1·01	0·53	0·56	0·80
3. ,, ,,	Seta, Kyagwe. Solitary tree 40 years old, total spread 6 metres across	1·29	0·71	0·24	0·17	0·46
4. ,, ,,	Kawanda Expt. Station. 7 years old, spacing 15 × 15 ft.	2·38	1·18	0·49	0·22	0·81
5.* ,, ,,	Kampala Plantation. 12 years old spacing 8 × 8 ft., clean weeded	1·77	0·65	0·31	0·22	0·58
6.* ,, ,,	Kampala Plantation. 12 years old, spacing 8 × 8 ft.; *Centrosema pubescens* cover	1·44	0·53	0·42	0·17	0·53
7.* ,, ,,	Kampala plantation. 12 years old, spacing 8 × 8 ft.; weeds slashed	1·31	0·92	0·42	0·19	0·57
8.* ,, ,,	Kampala Plantation. 12 years old, spacing 8 × 8 ft.; mulched with elephant grass	5·90	1·72	0·60	0·11	1·51
9. ,, ,,	Kawanda, Native plot, about 10 years old, spacing 8 × 8 ft.; trees dying through invasion by couch grass (*Digitaria scalarum*)	0·69	0·71	0·53	0·33	0·51
10. *Digitaria scalarum* (Couch grass)	rhizomes and roots from sample 9	2·32	1·92	0·61	0·27	0·99

The figures in Table 1 show that there were usually more roots of robusta coffee in the top 16 cm. of soil than there were in the 32 cm. of the soil at depths between 16 and 48 cm.; as there were so few roots

below 48 cm., it may be considered that usually at least half of the roots were in the top 16 cm. of soil. The natural distribution of robusta coffee roots was shown best in sample 3 from an isolated 40-year-old tree in a native garden in Kyagwe, east of Kampala, for there was no risk that the roots in this sample might have been mixed with those of other species, as in the case of the samples from the forest. The Kyagwe tree was typical of the fine old specimens to be found in native gardens in Uganda and in the Bukoba district of Tanganyika; these trees have a spreading habit, casting a dense shade over the ground beneath their canopy and producing such a mat of roots there that no weed-growth is possible and the soil is left quite uncultivated, so that the roots are undisturbed. The samples were all taken from underneath the canopy of the tree, but the roots extended for some distance out into the bare, swept ground of the compound in which it was growing.

It is noteworthy that the concentration of roots under the old tree in Kyagwe was much less than that of the roots in the plot at Kawanda, which consisted of spreading trees of the same type as that in Kyagwe, but which were only 7 years old; even though these trees were at a wide spacing of 15 ft., yet there was a much greater concentration of roots in the soil. As the old native trees in Uganda have grown and fruited so well with no cultivation of the soil, an attempt has been made to reduce to a minimum all cultivation on the coffee plots at Kawanda; if much cultivation had been practised, there would not have been such a concentration of roots near the surface of the soil.

A more detailed examination was made of the roots in the plot at Kawanda by taking another series of cores from each individual centimetre of soil below the surface to a depth of 8 cm.; it was much more difficult to take these samples than the bigger ones, as there was a tendency for the roots to remain attached to the soil below the layer sampled, and care had to be taken to cut them all off at the correct depth. The average lengths of roots per c.c. of soil at different depths were:

Depth below surface	*Length of root*
0–1 cm.	11·6 cm.
1–2 ,,	4·2 ,,
2–3 ,,	2·8 ,,
3–4 ,,	2·2 ,,
4–5 ,,	1·4 ,,
5–6 ,,	1·4 ,,
6–7 ,,	1·3 ,,
7–8 ,,	1·6 ,,

The average concentration of roots in the whole layer of soil sampled—down to 8 cm. below the surface—was 3·31 cm., a figure greater than that of the sample 4, which had been taken at random, whereas those for the individual centimetres of soil were taken only in places where there had obviously been no cultivation and the roots were undisturbed. The above figures show how great a concentration of roots there may be near the surface of the ground; one individual sample of 10 c.c. of top soil contained 226 cm. of roots.

The natural distribution of the coffee roots is altered by the treatment of the ground in which they are growing; this is shown by the figures of

samples 5, 6, 7, and 8 from adjacent small plots of an upright strain of robusta coffee on the Kampala Plantation. When this coffee was 9 years old, 4 different ground treatments were started on individual plots:

(*a*) Clean weeding, the weeds being removed by hand, leaving the ground undisturbed; this coffee continued to be in good health.

(*b*) With a permanent cover of *Centrosema pubescens*; this coffee was in fair health during the rainy weather, but suffered greatly in dry seasons.

(*c*) The weeds were slashed; at first they consisted of succulent annuals, but soon a cover of perennial grasses appeared; the coffee was in poor condition, stunted, with yellow leaves and no crop of fruit.

(*d*) Mulching with the leaves and stems of elephant grass (*Pennisetum purpureum*); this coffee was in much the best condition, with vigorous growth and heavy crops.

After 3 years the differences in the vigour of the coffee on the first 3 plots were much more striking in the growth of shoots and leaves than in the roots, although plots (*b*) and (*c*) had a smaller amount of root-growth. But the effect of mulching was most marked, producing an extraordinary development of roots in the surface-layers of the soil. Mulching usually has a most stimulating effect on coffee in Uganda; in the instances when the benefit has not been well demonstrated, it seems that the reason may lie in the practice of 'digging in the mulch', which is a violent form of root-pruning, destroying the mass of fine feeding-roots that have grown into the rotting material.

A major factor in the cultivation of any crop in the wetter areas of Uganda is the control of the local couch grass, *Digitaria scalarum*, which forms a dense mass of rhizomes and roots with which few other plants compete. Sample 9 was from a plot on an African farm at Kawanda; this coffee had been invaded by *Digitaria scalarum* some years ago and was in a state past recovery. Sample 10 records the lengths of rhizomes and roots of the couch grass that were found in the same soil cores together with the coffee roots; the figures show the abundance of grass roots in the upper layers of the soil. The coffee roots in these upper layers were much less than those in healthy plots and most of them were dark in colour, probably having lost their absorbing capacity; for, as Nutman has shown for arabica coffee, where there is dieback of the shoots of the bush there is also dieback of the roots. It is interesting to note that at depths below 16 cm., where there were fewer roots of the grass, the length of coffee roots was as good as that in healthy plots. But, in order to remove the couch grass completely, it would be necessary to dig so deeply and to disturb the coffee roots to such an extent that the coffee would need many years to recover its vigour; it is preferable in such circumstances to remove the coffee, to clean the ground, and to replant.

The Root Systems of Other Woody Tropical Crops

Robusta coffee is the only important permanent crop in Uganda which is native to the country; the others are all exotics but, like robusta coffee, they are plants of tropical forest growth. It appears to be a feature of

tropical forests that the bulk of the species in them are shallow-rooted, deriving the greater part of their nutrients from the relatively rich but shallow layer of soil near the surface on the forest floor. Therefore it was considered worth while to sample the roots of other permanent crops in Uganda: the sampling with an auger, the extraction, and the mounting of the roots was done in the same way as with those of the coffee, and the results are shown in Table 2.

TABLE 2. *Distribution of Roots of other Tropical Crops in Uganda*

	Average lengths (cm.) of roots per c.c. of soil at depths of:				
	0–8 cm.	*8–16 cm.*	*16–32 cm.*	*32–48 cm.*	*0–48 cm.*
11. *Coffea arabica.* Kawanda Expt. Station. 6 years old, spacing 10×10 ft.	0·45	0·29	0·22	0·21	0·26
12. *Coffea excelsa.* Kawanda Expt. Station. 6 years old, spacing 12×12 ft.	1·26	1·23	0·56	0·38	0·72
13. *Thea sinensis.* Kijura, Toro. 6 years old, spacing 5 ft. triangular	1·58	1·41	0·69	0·14	0·77
14. ,, ,, Senda, Mityana. 6 years old, spacing 5 ft. square	0·57	0·76	0·37	0·58	0·54
15. ,, ,, Bugumiya, Mityana. 16 years old, spacing 5 ft. square	0·19	0·45	0·49	0·34	0·39
16. *Theobroma cacao.* Botanic Gardens, Entebbe. 39 years old, spacing about 15 ft. square	0·61	0·32	0·27	0·19	0·31
17. *Hevea brasiliensis.* Kivuvu Estate, Kyagwe. 30 years old, spacing 20 ft. square	0·55	0·32	0·12	0·03	0·19
18. *Cinchona josephiana.* Kitubulu, Entebbe. 20 years old, spacing 6 ft. square	0·97	0·60	0·35	0·30	0·47
19.* ,, ,, Salama Estate, Kyagwe. 7 years old, spacing 5 ft. square	0·51	0·80	0·73	0·26	0·54
20. *Musa paradisiaca.* Kawanda, native farm. 10 years old, spacing about 15 ft. square	0·50	0·59	0·57	0·35	0·49
21. *Pennisetum purpureum.* Kawanda Expt. Station. 5 years old	4·96	1·81	1·27	0·52	1·69
22.* *Saccharum officinarum.* Buundu Estate, Kyagwe. 3 years old, rows 4½ ft. apart	0·50	0·74	0·80	0·49	0·64
23. *Zea mays.* Kawanda Expt. Station. 4 months old, spacing 3×2 ft.	1·08	1·07	0·77	0·70	0·85
24. *Cajanus cajan.* Kawanda Expt. Station. 2 years old	0·37	0·39	0·19	0·06	0·20
25. *Gossypium hirsutum.* Kawanda Expt. Station. 4 months old, spacing 3×1 ft.	0·02	0·11	0·03	0·00	0·04

* Samples taken with soil auger graduated in inches

The plots of arabica and excelsa coffee which were sampled at Kawanda were close to that from which sample 4 of robusta coffee roots had been taken and were on similar soil. In spite of the resemblance between the conditions under which they were growing, there were marked differences between the length of the roots in the plots of robusta and arabica coffee. The arabica coffee roots were not so much concentrated near the surface of the soil but had a distribution resembling that of arabica coffee roots in acid soils recorded by Nutman [2]; in the case of bushes growing on neutral volcanic soils he found that even more of the roots were at a distance below the surface. Investigations in Puerto Rico have shown a shallow root-system of arabica coffee there, with 95 per cent. of the root in the top 12 in. of soil [4].

The root-system of excelsa coffee resembled that of robusta coffee rather than that of arabica coffee: the roots seemed to be concentrated in the upper layers of soil. Such a distribution was to be expected from the facts that excelsa coffee is found in association with robusta coffee in the

moist hollows of some forests and that the wild trees often have a well-developed system of lateral roots spreading near the surface of the soil.

In the case of tea (*Thea sinensis*) there was an interesting contrast between the results of sample 13, taken in Toro, and samples 14 and 15, taken at Mityana. The Toro tea was growing on heavier soil than that at Mityana, a fact which might in part explain the differences in root-distribution, there being many more shallow roots in Toro than at Mityana; but an important factor had been the amount of cultivation—the soil at Toro had been little disturbed, but that at Mityana had been deeply dug in order to eradicate couch grass.

Cacao (*Theobroma cacao*) also had most of its roots near the surface of the soil, and so did the Para rubber tree (*Hevea brasiliensis*); it was surprising that this latter species, which has a well-marked tap-root, should have had so few feeding-roots at depths below 16 cm. *Cinchona josephiana* (a broad-leaved vigorous form of *C. ledgeriana*), which does not possess a well-developed tap-root even when it is a seedling, yet had more roots at the lower depths than did Hevea; this distribution was shown both on light soils at Kitubulu near Entebbe and on heavy soils in Kyagwe (samples 18 and 19).

The Root-system of some Non-woody Tropical Crops

Sample 20 was taken in a native plantain garden at Kawanda and showed that the roots of this herbaceous plant (*Musa paradisiaca*) differed from those of the woody species sampled in that they were not concentrated near the surface, but were more abundant at depths of 8 to 32 cm. It may be on account of this relatively deep-seated root-system that the plantain is a suitable plant to utilize as temporary shade for coffee and cacao, whose seedlings develop a mass of roots near the surface.

Elephant grass (*Pennisetum purpureum*) plays a very important part in the agricultural economy of some parts of Uganda, colonizing the ground after it has been abandoned and, by the action of its roots, restoring its fertility. Sample 21, therefore, was taken to afford a comparison between the roots of this grass and those of cultivated crops; the figures that were recorded were under-estimated, for the grass roots had a great quantity of lateral branches, which were so many and so short that it was not feasible for them all to be mounted in lines; the actual length of root was probably 50 to 100 per cent. more than was shown by the measurements. Nevertheless, the figures show a great development of roots, far greater than that of any of the permanent crops, and it is to be expected that this grass would have a most beneficial action in restoring fertility [5].

Samples were also taken in a sugar plantation of variety P.O.J. 2725 at Buundu Estate in Kyagwe; as in the case of the plantain, most roots were found at depths between 8 and 48 cm. Maize (*Zea mays*), pigeon pea (*Cajanus cajan*), and cotton (*Gossypium hirsutum*) at Kawanda were also sampled. In each case there was no concentration of roots near the surface, but most of them were at some depth in the soil. The surface-rooting habit appears to be a quality peculiarly suited to plants growing

naturally in closed forest conditions; the herbaceous crops, whose habitat is not in dense forests, are relatively more deep-rooted.

Discussion

Lateral spread of roots.—If the roots of a plant were so shallow, it might be expected that they would have a wide lateral spread. This factor was well demonstrated by excavating carefully the root-system of a 5-year-old robusta coffee bush at Kawanda, illustrated in Plate 10. It was not feasible to wash out the root-system, so the soil was scraped away by hand carefully, retaining as many as possible of the roots. There was a distinct tap-root, terminating abruptly at a depth of about 45 cm.; there were very few branches to this tap-root and these had very few fine roots on them. The main feeding-root system of the plant was composed of a plate of roots, some of them extending just below the surface of the soil to a distance of 245 cm. from the trunk of the bush before they diminished to less than 3 mm. in diameter. The wide, shallow root-system had developed although deep holes had been dug before the coffee was planted and the bushes had been very closely spaced—only about 8 ft. apart—before they were thinned.

When there is room for them to extend farther, the roots of robusta coffee have a much wider spread. As elephant grass has such an important function in Uganda for regenerating soil, it has been suggested that it might be used for interplanting among other crops. Samples were taken at intervals of 3 ft. across a bare strip of ground, 21 ft. wide, between blocks of robusta coffee and of elephant grass, both of them 4 years old. It was found that the coffee roots could be traced for a distance of 18 ft. and that the elephant grass could be traced for at least 12 ft.; throughout most of the ground the two species were in competition, and it was the roots of the grass which would be the more powerful in this competition for food and water. The edge effect of elephant-grass strips has been very noticeable at Kawanda; e.g. in plots of cotton, the rows nearest the grass have been very stunted.

Planting.—The fact that a very large part of the feeding-roots of robusta coffee and of other permanent crops in Uganda are so close to the surface of the soil has an important bearing on the problems of planting and cultivation. For one thing, if so few of the feeding-roots are produced at any distance below the surface of the soil, is it worth while to make big holes before planting? In order to test this point, the robusta coffee which has been planted at Kawanda during the last 3 years has been put into ground which had been deeply dug, but in which no large holes had been made; an excellent stand has resulted, the coffee has made excellent growth and has commenced to ripen its first crop of fruit within 2 years of the date of planting.

The seedlings of some tropical crops, notably tea and the Para rubber tree, have well-developed tap-roots; when the seedlings are lifted for planting, care must be taken to retain as much as possible of these tap-roots and care must be taken that they are not broken or twisted in planting. Yet, when the seedling produces new roots, they do not arise from the cut ends of the tap-root, but are formed in a ring at its top, just

below the surface of the soil; careful examination of young coffee seedlings has shown that the main lateral roots of the plant often arise from the hypocotyl and not from the radicle of the seedling. There seems to be little doubt that the importance of the tap-roots of these seedlings lies in their function as storage organs for reserves of food and water rather than as absorbing organs; for, even when crops are sown at stake, as is sometimes done with tea in Uganda, the tap-root may be well marked for the first few years of the life of the plant, but with increasing age it becomes less and less conspicuous in comparison with the lateral roots. (I have seen a plot of tea in Ceylon, over 50 years old, being grubbed out in order that the ground might be replanted; none of the bushes showed any evidence of a definite tap-root—there was a mass of almost equal roots radiating in all directions.)

If large holes are dug for any permanent crop and if the soil is not made firm during the process of planting, the plants will sink to a depth in the field greater than that which they occupied in the nursery beds; such deep planting has a very bad effect on the growth of the crop. It is especially marked with arabica coffee, as has been shown at the Coffee Research Station, Lyamungu, Tanganyika [6]; with robusta coffee the growth is retarded, though not to the same extent. Bad effects of deep planting also may be seen with rubber and tea. Cinchona suffers greatly if it is planted too deeply, for not only is the growth of the plant checked, but also the stem is liable to be attacked by collar rot; therefore it is better to dig the ground very deeply for this crop and to excavate only shallow hollows with the hands for planting. It seems that the same procedure might with advantage be adopted in planting other crops—that a better result would be achieved if money were spent in a general thorough cultivation of the land instead of merely in digging deep holes on the spots where the plants are to be placed.

Especially large holes are usually dug when seedlings are to be planted in the blank spaces of established plots of coffee or tea. In such cases it is better to emphasize the width of the holes, rather than their depth, for root-competition from the surrounding plants will come more from the sides of the holes than from below; a hole 6 ft. wide and 1 ft. deep will cost less to dig than a hole 3 ft. wide and 2 ft. deep, and it will be of more benefit to the young plant. In any case where deep holes are dug, it is best to make each layer of soil firm as it is replaced, pounding it with a stick, rather than trusting to the hands and feet of the labourers. If the soil is heavy in texture, this consolidation cannot be done when it is very wet, or the soil may be beaten into a cake.

Cultivation.—When so large an amount of crop roots is confined to the upper layers of soil, it can be understood that the growth of any weeds, even of small, shallow-rooted, annual ones, will increase the competition for supplies of water and mineral nutrients; when perennial rhizomatous grasses are present, the competition is greatly intensified. It is in the control of weed-growth that there lies the main value of cultivation. Recent work on temperate crops [7] has shown that cultivation, for cultivation's sake, is of little benefit to the crops and may even depress yields. Similarly, in the case of tea, Eden [8] has shown that both weed-

growth and intensive cultivation will reduce yields by 8·6 per cent. and 5·3 per cent. respectively, in comparison with clean weeding. Until a few years ago it was the general custom in Assam to dig through the tea gardens very deeply once a year; it is now recognized that this practice, which entails great damage to the root-systems of the bushes, depresses yields; cultivation is being reduced and on many estates the weeds are kept down merely by scraping the soil.

It is hard to understand how belief in the value of deep digging can have arisen. It may be that, as in the case of many other mistakes in tropical agriculture, it was by analogy with the methods of farming in temperate regions, where deep cultivation and the consequent root-pruning of temperate fruit crops may restrict vegetative growth and stimulate fruiting—which is quite contrary to what is desired in the case of most tropical crops. The distribution of the roots of an apple tree on a vigorous stock is very different from that shown by the samples taken of the various tropical woody crops in Uganda; the only temperate fruits which form a mass of fine roots near the surface, like those of robusta coffee, are raspberries and currants, crops in which cultivation is usually reduced to the minimum.

Permeability.—One reason which is often put forward in favour of deep cultivation is that it should increase the permeability of the soil, enabling air and water to enter more readily. But Eden [8] has shown that there is little difference in the soil resistance of tea plots in Ceylon, whether they have been given normal cultivation, clean weeding, or no cultivation. The soil resistance of many of the plots sampled for roots in Uganda was measured by counting the number of knocks required for the Veihmeyer auger to penetrate into the soil, and the results are embodied in Table 3. All the samples were taken during the rainy season, when the ground was moist.

TABLE 3. *Soil Resistance on Plots Sampled*

Plot	*Average number of hits for auger to penetrate*				
	0–8 cm.	*8–16 cm.*	*16–32 cm.*	*32–48 cm.*	*0–48 cm.*
2. *Coffea canephora.* Itwara Forest, Toro. Wild trees.	1·7	6·6	18·4	21·9	48·6
3. ,, ,, Seta, Kyagwe. Solitary tree 40 years old	4·2	6·0	24·9	34·9	70·0
4. ,, ,, Kawanda Expt. Station. 7 years old	3·7	5·7	27·3	76·1	112·8
9. ,, ,, Kawanda, native plot. About 10 years old, invaded by couch grass	7·9	11·4	26·7	36·3	82·3
11. *Coffea arabica.* Kawanda Expt. Station. 6 years old	2·2	5·3	40·7	103·6	151·8
12. *Coffea excelsa.* Kawanda Expt. Station. 6 years old	3·6	6·2	42·8	91·6	144·2
13. *Thea sinensis.* Kijura, Toro. 6 years old	1·7	3·5	15·6	24·4	45·2
14. ,, ,, Senda, Mityana. 6 years old	4·2	15·8	52·7	42·9	115·6
15. ,, ,, Bugumiya, Mityana. 16 years old	2·9	3·4	15·0	34·7	56·0
16. *Theobroma cacao.* Entebbe Botanic Gardens. 39 years old	7·1	16·8	46·9	56·1	126·9
17. *Hevea brasiliensis.* Kivuvu Estate, Kyagwe. 30 years old	4·3	9·3	23·8	32·5	69·9
18. *Cinchona josephiana.* Kitubulu, Entebbe. 20 years old	2·3	3·4	9·5	11·3	26·5
20. *Musa paradisiaca.* Kawanda, native farm. 10 years old	5·3	10·8	29·3	53·7	99·1
21. *Pennisetum purpureum.* Kawanda Expt. Station. 5 years old	3·5	7·5	25·9	39·2	75·1
23. *Zea mays.* Kawanda Expt. Station. 4 months old	2·2	4·5	25·7	46·0	78·4

The soils which were hardest to penetrate were those of samples 4, 11, 12, 14, and 16; in each case an average of more than 100 hits of the hammer was needed to make the auger penetrate 48 cm. into the soil.

With the exception of 16, these were some of the youngest plots sampled; they had all received recent cultivation, for sample 16 was from a plot of cacao at Entebbe which had been much dug in order to rid it of couch grass. The most easily penetrated soil was that of the cinchona plot near Entebbe, sample 18, which had not been cultivated to any depth for 15 years, as it had formed a shade so dense that few weeds could grow there; but this plot was on a soil of lighter texture than that of most of the other plots. Samples 2 and 13 were on soils containing much clay, yet were easily penetrated; no cultivation at all had been given to the soil of sample 2 during the time that it had been under secondary forest, a period of at least 50 years. Little deep forking had been given to the tea of sample 13 after the time of planting, in contrast to a great deal of deep digging on sample 14, of about the same age, which was on a soil with less clay-content, but which nevertheless was more difficult to penetrate.

Samples 4, 11, 12, and 21 were taken on the same slope of the Kawanda Experiment Station, on land which had been under native plots until about 7 years before the samples were taken. The first three samples, which were under coffee, all showed a hard pan of soil at depths below 30 cm.; this pan appears to have been caused by the native method of cultivation—turning over the top layers of soil with a hoe to the same depth time after time—so that it is not surprising that a hard layer should be formed beneath. Sample 21, of the roots of elephant grass (*Pennisetum purpureum*), was taken from similar soil nearby but was much more easily penetrated; this is an illustration of the value of grasses in restoring the structure of the soil, a subject discussed by Martin [5]. The soil profile of the sample 3, taken from under an old coffee tree in Kyagwe, was very like that of the samples at Kawanda; but this soil, which had been cultivated for at least 20 years, did not exhibit so hard a subsoil as that of the more recently cultivated land at Kawanda.

It is not possible to make very definite statements from scattered samples, taken from different soils, but the figures given in Table 3 suggest that cultivation of the soil may not make it more permeable, but may have the opposite effect of making it more difficult to penetrate.

Root competition.—The struggle between the aerial parts of plants for light is a major factor of plant competition in temperate zones. The same struggle may be seen in tropical vegetation, but it appears that the competition below ground between the roots of different species is often of greater importance. For example, the forest climax in the wetter parts of Uganda consists of a pure stand of *Cynometra alexandrii*, a tree whose canopy is much lower than that of the more soft-wooded species it displaces. Many of the trees which are displaced have seedlings which are tolerant of deep shade—some of them, like those of *Entandophragma utile*, will not grow in full sun; the only reason why such seedlings cannot regenerate under Cynometra seems to be that they cannot compete with its roots.

It is a feature of many indigenous systems of tropical agriculture that the crops are grown in admixture and not in pure culture, as is the case in temperate farming; and it is probable that one reason for the

practice of interplanting is that better use of the land may be achieved by growing together crops whose roots occupy different layers of soil. Similarly, many permanent tropical crops benefit from being interplanted with shade trees. There appear to be many reasons why shade trees are of benefit to the crop; one reason is that crops whose natural habitat is in forests may be able to assimilate better in shady conditions than in full sunlight, as Nutman has shown to be the case with arabica coffee.

Overhead shade is also useful because it helps to control the temperature of the soil in which the crop is growing; soil temperatures were recorded for about 3 years in the plots of robusta coffee at Kampala and showed that at 3.30 p.m. (which would be approximately the time of the maximum at that depth) the temperature of the soil 2 in. below the surface of the clean-weeded plot was on occasion as much as 35° or 40° C.—a temperature which must be inimical to root-growth; whereas in plots which were protected by overhead shade or by mulch, these excessive temperatures were not recorded and the soil was as much as 10° C. cooler, an important circumstance in the cultivation of a shallow-rooted crop.

There is no doubt also that the action of the roots of the shade trees on the soil is also important; some may bring nutrients to the surface by a siphon effect; some leguminous trees may fix atmospheric nitrogen by means of their root-nodules. Tree roots, by their growth and decay, make the soil more permeable. But it must be remembered that, if the roots of the shade trees occupy the same layers of soil as do those of the crop plants, there may be competition for supplies of water and nutrients. As most of the crops have the bulk of their roots near the surface, it is better to employ shade trees with deep roots; if it is necessary to use a species of shade tree which forms a mass of surface roots, as in the case of *Acacia decurrens* on the higher tea plantations in the Nilgiri Hills of South India, the crop plants may be forced to make a root-system below that of the shade trees.

A species of shade tree which is suited to one crop may not be suited to another; for example, robusta coffee flourishes under the shade of the barkcloth tree (*Ficus natalensis*) in Uganda, but tea grows badly under it. Until more is known about the root-systems of shade trees and their actions, it is best to plant only those whose compatibility with specific crops under specific conditions has been proved. *Leucaena glauca* has proved to be a most useful cover crop for coffee; it has a long tap-root, with few lateral branches, which is in great contrast to the mass of surface roots produced by robusta coffee; and it is probably on account of this difference that the two species grow well together under such diverse conditions of soil and climate as are to be found in Uganda and in the Netherlands East Indies. But, under the dry conditions of Uganda, the competition of Leucaena roots will stunt the growth of young coffee.

The average annual rainfall of the parts of Uganda where most permanent crops are grown is only about 50 in.—a much smaller amount than is regarded as essential for such crops in other countries. It would not be possible to cultivate these crops so successfully in Uganda if it

were not for the facts that the rainfall is very well distributed throughout the year and that little of it is lost in run-off, as it is seldom that more than 2 in. of rainfall is recorded in 24 hours. Nevertheless, the supply of water is a limiting factor to production in the Protectorate, and there is competition for soil moisture not only between the crops and the shade trees but also between the crop plants themselves.

If tea is planted at a spacing of 4 ft. square, each plant can draw its supply of water from 16 sq. ft. of soil; if the spacing is 5 ft. square, each plant has 25 sq. ft. of soil—half as much again. There is much evidence that, under the relatively dry conditions of Uganda, it is better to grow crops at wider spacings than are employed in other, wetter, tropical countries. It is a mistake to plant permanent crops at too wide a spacing at first, for the young plants make better progress if they are fairly close together or if some intercrop, like pigeon pea or plantains, is provided; there seems little doubt that the shelter of the young plants and of the soil from excessive heating by the sun is important.

Under Uganda conditions, however, it is essential that when the plants have grown to maturity, they should not be too close together; much loss has been incurred on estates through failure to remove the interplanted crops, such as arabica coffee in rubber, at the right time; they have been left with the idea that both the temporary crop and the permanent crop should give some return, with the result that both have been unprofitable. The breeding plots of robusta coffee on the Kawanda Experiment Station have been thinned to wide spacings, so that the individual plants may be able to develop to their full size, rather than that heavy yields per acre may be obtained; the erect forms which are pruned to have a succession of stems, as on the Agobiada system, are at a spacing of 12 ft. square and the spreading forms, which are not pruned but are trained into low trees, are at a spacing of 15 ft. square. In spite of these wide spacings and of the facts that the soil is not rich and that there are several blank spaces, the erect forms have given an average yield of about 17 cwt. clean coffee per acre for the last 2 years, and the spreading forms an average yield of about 14 cwt. per acre. These yields compare very favourably with those from more closely planted plots of robusta coffee on estates; if good crops are to be obtained from closely planted bushes, they must be drastically pruned. There is one interesting feature of the Kawanda coffee plot spaced at 15 ft. square—the bushes inside the plot are much better than those on the outside, probably because they are more sheltered; it is usually found that the outside rows of a coffee plot are the best, as the plants in those rows have more room for their roots.

Tea also responds to wide spacings under dry Uganda conditions and, in spite of the low rainfall, heavy yields are obtained from plots planted at the wide spacing of 5 ft. square. The bushes are very large, and form a complete cover over the ground; this is a great advantage for, if so many of the roots of the crop are close to the surface, the soil should be shaded from the full heat of the sun. If tea or coffee is to be widely spaced, it is an advantage to plant in triangles rather than on the square, as a more even cover is given to the ground. In theory, the triangular

spacing would also allow more even distribution of the roots; but it seems that in practice, as the roots spread far beyond the branches of tea or coffee bushes, they will develop so as to utilize the whole ground area to the best advantage, whereas correct planting and pruning are needed to ensure an even distribution of the branches above ground.

The wide spacings advised for coffee and tea under Uganda conditions would not give optimum yields in wetter countries, where the supply of water is not a limiting factor to plant growth. In Ceylon, for example, the present tendency is to adopt closer and closer spacings for tea, and to maintain the supply of nitrogen in the soil—usually the limiting factor in production—by heavy manuring.

Erosion control.—The practice of clean weeding, with a minimum of cultivation, which has been carried out in the coffee plots at Kawanda for the last few years, has given very satisfactory results; the coffee has grown well and cropped well; and the cost of cultivation is now very low. The ground near the stems of the coffee is under dense shade, especially that under the trees of the spreading types, and few weed seeds germinate there; even in the open spaces between the coffee, the weeds grow slowly, not because the surface of the ground is too hard, but because of the mass of coffee roots with which the young seedlings must compete.

Although the rainfall at Kawanda is light, the control of erosion is important; the coffee was planted on land which had been seriously gullied under native plots. Yet the construction of narrow-base bunds at vertical intervals of 3 ft., coupled with the avoidance of needless hoeing, has prevented any trace of the loss of water from the surface; the felt of roots seems to act like a sponge, absorbing the rain from the heaviest storms. The ditches below the bunds are cleaned out about once a year and the soil in them is thrown on the upper side of the banks; this process has resulted in the terracing of the soil, for the land between the bunds is nearly horizontal—a phenomenon which must be due to the slow movement of the soil between the coffee roots, the process called 'soil creep' in U.S.A. Similar control of erosion by the plant roots may be seen in some Uganda forests where, in spite of the steep slopes, and although there is little undergrowth or cover on the soil, yet there is no loss of water; but, if the surface of the soil is made hard by the trampling of stock, erosion starts quickly.

The control of erosion, by allowing the roots to form a protective mat near the surface of the soil, has been achieved in Uganda with a relatively light rainfall and on a heavy soil; it does not follow that similar results would be achieved if the rainfall was heavier and the soil was lighter; in fact, clean-weeding has had very bad results on rubber plantations in Malaya and the East Indies. It is probable that the growth and the distribution of roots are greatly influenced by differences in soils and climates. It is certain that there is a great need for the thorough study of the root-systems of the various tropical crops and of the reaction of the roots to different soil treatments.

Root studies and plant selection.—The importance of root studies is not confined to problems of cultivation; it also has a great bearing on the problems of plant selection. Seedling progenies of different strains of

robusta coffee in Uganda, of the same age and grown in adjacent nursery beds, have shown marked differences in their root-systems, some being long and little branched, others being shorter and much more fibrous. Studies of the root-stocks of fruit trees in temperate regions have shown that differences in the morphology of the roots may be correlated with differences in the physiology of the plants, of their rate of growth, of their habit, and of their precocity in fruiting. These same characters are of great importance in tropical crops and, if selection is to be carried out to the best advantage, attention must be paid not only to the parts of the plant above ground, but to their roots as well; Evans [9] has shown the importance of this aspect of sugar-cane breeding.

Summary

1. A short description is given of the distribution of the roots of robusta coffee, as shown by the measurement of the roots contained in cores taken with a soil auger to a depth of 48 cm. It was found that when the plants are allowed to grow without interference, there was a great concentration of feeding-roots very close to the surface of the ground. Different methods of cultivation, and the presence of noxious grasses, had marked effects on the amount and the distribution of the roots.

2. The root-systems of other woody crops were also examined in the same way, and it appeared that in the case of some crops—tea, cacao, Para rubber, and excelsa coffee—most of the roots were in the top 16 cm. of soil; others—arabica coffee and cinchona—had a larger proportion of their roots below this depth.

3. Some non-woody crops were also examined; it was found that, in the case of the plantain, there was a greater concentration of roots at depths between 8 cm. and 32 cm. than near the surface; a similar result was found with the roots of sugar-cane. Maize, cotton, and pigeon pea, which were short-lived crops, all had a more deep-seated root-system than that of the woody crops, and it is suggested that this may be attributed to the fact that they originated from plants whose natural habitats were not in forests, as in the case of the woody crops.

4. The bearing of the shallowness of the root-system of woody tropical crops on cultural practices—planting, spacing, hoeing—is discussed; and it is suggested that the study of the root-systems is important not only in regard to the problems of cultivation, but also in the selection of the crops.

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REFERENCES

1. A. S. THOMAS, The Wild Coffees of Uganda. Empire J. Expt. Agric., 1944, **12**, 1–12.
2. F. J. NUTMAN, The Root System of *Coffea arabica*. I. Root Systems in Typical Soils of British East Africa. Ibid., 1933, **1**, 271–96.
3. —— The Root System of *Coffea arabica*. III. The Spatial Distribution of the Absorbing Area of the Root. Ibid., 1934, **2**, 293–302.
4. J. GUISCAFRE-ARRILLAGA and L. A. GOMEZ, Studies of the Root System of *Coffea arabica* L. Pt. II. Growth and Distribution in Catalina Clay Soil. J. Agric. Univ. Puerto Rico, 1940, **24**, 109–17.
5. W. S. MARTIN, Grass Covers in their relation to Soil Structure. Empire J. Expt. Agric., 1944, **12**, 21–32.
6. S. M. GILBERT, Annual Report of the Coffee Research Station, Lyamungu, 1940.
7. H. C. PEREIRA, Crop Response to Inter-Row Tillage. Empire J. Expt. Agric., 1941, **9**, 33.
8. T. EDEN, Studies in the Yield of Tea. IV. The Effect of Cultivation and Weeds on Crop Growth. Ibid., 1940, **8**, 32, 269.
9. H. EVANS, The Root System of the Sugar-Cane. II. Some Typical Root Systems. Ibid., 1936, **4**, 208–20.

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The Root-system of a five-year-old bush of Robusta Coffee.

The root-system has been excavated and inverted and is photographed with a metre-ruler for comparison. There is a distinct, short and little-branched tap-root and a plate of lateral roots spreading near the surface of the ground.

DEVELOPMENT OF LIVESTOCK IN TANGANYIKA TERRITORY

VI. THE DEVELOPMENT OF MUTTON QUALITIES IN MASAI AND GRADE BLACK-HEADED PERSIAN SHEEP

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HAIR-COATED, fat-tailed or fat-rumped sheep are common in the hot, dry, and less fertile areas of Africa. These animals mature slowly and yield small carcasses of poor mutton qualities. Tropical animal-husbandry schemes are concerned with the improvement of the mutton capabilities of these sheep so that the maximum amount and quality of human food may be produced. As Hammond [1] has pointed out: 'A study of the changes which take place in the conformation of the animal from birth to the adult condition, and the manner in which these changes are brought about, lies at the root of the improvement of animals for meat-producing purposes.' Much information is available concerning the development of mutton quality in improved British breeds, but there are no corresponding data for fat-tailed types. A preliminary study [2] has shown that the fat-tailed types possess very different conformation and ratios of muscle : fat : bone from improved mutton breeds; this paper deals more fully with the age-changes in two Tanganyika types.

In the earlier paper the various types of Tanganyika sheep were briefly described, and in this work the age-changes in body composition have been followed in Masai and $\frac{3}{4}$-grade Black-headed Persian $\times$ local long-tailed wethers. The same terms and the same methods of dissection and measurement have been used as before [2], and the whole investigation is modelled on Hammond's classical study of British breeds [1].

Table 1 summarizes the results on Masai and Grade Black-headed Persians (B.H.P.), and shows how proportions and weights of the different organs change with age. The figures for B.H.P. agree with those published earlier [2], and in most cases the weights are below those of Masai sheep of the same age. Masai sheep yield slightly smaller carcass percentages, but their proportions of head, skin, and alimentary tract are higher than in B.H.P. or long-tailed indigenous sheep. The proportions of blood, heart, spleen, genitals, tongue, and lights are about the same for all these types, but Masai liver percentages are slightly smaller. The omental-fat proportions are rather variable, but generally are highest in Masai sheep.

Owing to the greater size of Masai sheep, the skin might be expected to form a smaller proportion of the total weight than in B.H.P., but the reverse holds true. This may be correlated with the general skin appearance in the two types: in Masai sheep the skin is often covered

TABLE 1. *Relative Proportions of the Organs and Tissues as Percentage of Empty Live-weight*

Breed	*Age in months*	*Number of animals*	*Live-weight in gm., empty*	*Carcass (hot)*	*Blood*	*Skin (with feet)*	*Head (without skin and tongue)*	*Heart*	*Liver*	*Lights*	*Spleen*	*Genitals*	*Tongue*	*Omental fat*	*Alimentary tract*
Grade Black-headed Persians	6	2	8,603	46·4	8·6	15·2	8·0	0·5	2·1	2·2	0·2	0·6	0·5	0·3	15·4
	8	2	9,973	54·7	5·9	13·2	6·1	0·6	2·4	2·2	0·2	0·5	0·4	0·6	13·2
	10	1	16,094	60·0	5·4	11·9	7·1	0·6	2·0	1·7	0·2	0·2	0·4	0·6	9·9
	12	2	18,891	60·2	5·2	11·6	6·5	0·5	1·9	1·7	0·2	0·3	0·5	2·9	8·5
	14	1	19,738	62·4	5·1	13·1	5·9	0·5	1·9	1·8	0·2	0·2	0·4	0·5	8·0
	16	2	21,398	62·4	4·9	9·6	6·4	0·5	1·9	1·6	0·2	0·6	0·3	2·9	8·7
	18	1	25,842	64·6	5·7	8·9	5·6	0·4	1·8	1·4	0·2	0·1	0·4	1·9	9·0
	28	4	44,225	67·9	3·5	8·2	4·8	0·3	1·0	1·2	0·1	0·5	0·2	4·7	7·6
Masai	12	1	18,728	57·8	5·4	13·3	7·7	0·6	2·1	1·8	0·3	0·3	0·3	1·3	9·2
	14	1	24,786	59·2	5·4	13·3	6·7	0·5	1·4	1·6	0·2	0·1	0·3	2·0	9·3
	16	1	27,587	61·3	5·1	11·9	6·5	0·4	1·4	1·5	0·2	0·1	0·3	2·0	9·2
	18	1	29,692	58·0	4·9	12·4	6·8	0·5	1·5	1·7	0·2	0·4	0·3	2·2	11·1
	20	1	35,965	61·7	4·5	11·7	6·1	0·4	1·4	1·4	0·2	0·1	0·2	2·7	9·5
	28	1	58,400	69·0	2·8	8·9	4·6	0·3	0·9	0·9	0·1	0·7	0·2	5·3	6·3

with long hairs and hangs in loose folds, whereas in B.H.P. the skin is stretched smooth and is covered with short fine hairs.

Carcass percentages of adult local sheep compare well with Hammond's figures for improved mutton breeds, but, as will be seen later, this is due to their large adipose deposits. When adult local types are compared with Hammond's semi-wild animals, the latter have smaller carcass proportions but larger percentages of head, pluck, skin, and blood. The higher omental-fat percentages in local sheep show how much more fattened they are than the Shetland and Soay rams examined by Hammond. The present data indicate that the alimentary tract forms an unusually high proportion of the total weight in local sheep; this is probably connected with the hard, fibrous, and bulky nature of the grazings to which fat-tailed sheep have become adapted.

Compared with improved mutton types, local sheep have heavier proportions of head but smaller proportions of pluck and skin. The skins are relatively lighter owing to lack of wool. The development of the different organs and their relative proportions show age-changes of the same nature as reported by Hammond for improved types. The carcass percentages increase with age and degree of fattening. Omental-fat percentages increase in the same way and reduce the carcass proportions in the more fattened animals. With the increase in carcass and omental-fat proportions, the percentages of most other organs decrease with age.

Relative Weights of the Joints in the Carcasses

Since Masai sheep have heavier carcasses it is only to be expected that they will have heavier joints than B.H.P. at corresponding ages. If we compare carcasses of the same weight, the B.H.P. has smaller legs and shoulders but a heavier tail. The proportions of the joints in the hot carcass also show this same difference between B.H.P. and Masai sheep. The figures in this study (Table 2) compare satisfactorily with previously published data for B.H.P. [2], but indicate that Masai have heavier legs and shoulders and much smaller tails than local long-tailed sheep. There is no evidence that any one of these three types yields a carcass with a better distribution of weight between the joints than the others.

Compared with improved mutton breeds, local sheep have proportionally heavier necks but smaller legs, shoulders, loin, and thorax. If the local data are calculated as a percentage of the carcass-minus-tail, the loin proportions in adult fat sheep are the same as for Suffolk rams, but this is due to excessive subcutaneous fat rather than to the loin being as equally well developed as in improved mutton animals. Hammond's data show that unimproved breeds have proportionally heavier necks, legs, and shoulders, but smaller percentages of thorax, loin, and kidney-fat than improved types. The proportions in local adult sheep are intermediate between those in Hammond's improved and semi-wild breeds; the earlier developing joints have proportions more similar to the semi-wild types, but the later maturing joints have proportions

TABLE 2. *Relative Proportions of the Joints in the Hot Carcass*

Breed	*Age in months*	*No. of animals*	*Hot carcass weight in gm.*	*Neck*	*Shoulders*	*Thorax*	*Loin*	*Legs*	*Tail*	*Kidneys*	*Kidney fat*	*Loss on jointing*
Grade Black-headed Persians	6	2	3,992	9·8	20·6	26·3	12·9	26·8	1·3	1·0	0·5	0·8
	8	2	5,450	9·8	20·0	22·5	13·5	27·1	3·8	0·8	0·9	1·6
	10	1	9,652	9·7	18·2	22·6	14·6	26·3	7·3	0·6	0·3	0·4
	12	2	11,376	9·5	17·6	24·0	14·7	28·5	3·3	0·5	1·6	0·3
	14	1	12,326	9·2	16·4	20·2	15·9	23·9	11·0	0·4	0·7	2·3
	16	2	13,362	9·1	17·4	20·8	16·6	24·8	7·8	0·4	1·5	1·6
	18	1	16,693	9·0	16·6	22·6	17·0	24·7	6·7	0·4	2·1	0·9
	28	4	30,019	8·5	15·0	23·8	18·0	20·8	8·4	0·3	4·4	0·8
Masai	12	1	10,826	9·4	21·8	18·4	14·7	30·7	2·6	0·7	1·4	0·3
	14	1	14,669	10·1	18·9	21·4	14·6	28·2	3·9	0·4	1·7	0·8
	16	1	16,919	8·2	19·2	22·4	16·7	26·4	4·6	0·4	1·6	0·5
	18	1	17,214	10·8	18·4	23·8	15·0	23·4	6·6	0·6	1·0	0·3
	20	1	22,187	9·0	18·4	23·5	14·9	26·9	4·4	0·4	2·0	0·5
	28	1	40,322	9·8	13·6	22·2	18·2	20·7	9·7	0·2	5·0	0·6

close to those of improved breeds owing to their large deposits of subcutaneous fat.

The age-changes in the proportions of the joints in fat-tailed sheep are seen to follow the same trends as reported by Hammond for improved mutton breeds. The neck, shoulder, and leg proportions decrease with age, whilst the loin increases. Whereas Hammond found an increase in the proportions of the thorax with age, the thorax varies unevenly in B.H.P. carcasses, but shows a tendency to increase in Masai sheep. As was found previously [2], the absolute and proportional weights of the tail vary considerably between individuals, and it appears that the shape and size of the tail have more influence on its proportions than either age or degree of fattening. Since fattening is a normal attribute of age, an increase in the degree of fatness produces similar changes in the proportions of the joints as occur with age. In the data recorded in this paper a big difference in the proportions occurs between sheep of 28 months and sheep of 18 to 20 months of age. The age-difference has in these instances been exaggerated by the great increase in fatness that has occurred; in fact, the 28 months old Masai wether had become 'over-ripe' and the fat was soft and greasy.

Composition of the Joints

Table 3 gives the composition of the various joints in terms of muscle, fat, bone, &c. The main change in the composition of the joints with age is an increase in the amount of fat. This naturally reduces the proportional amounts of bone and muscle, but since muscle weight increases with age to a much greater extent than bone weight, the decrease in the proportional amount of bone is more marked than in the percentage amount of muscle.

When Masai and B.H.P. joints are compared it is seen that the bones of the former are not only heavier but form a higher proportion of the total weight of the joints. On the other hand, except for the over-fat animals, the proportional amounts of fat in the joints are usually higher in the B.H.P. but muscle percentages are less regular. Although Masai sheep have shorter tails than B.H.P., the figures obtained show that the actual and relative weights of muscle and bone are higher in Masai tails.

The figures for B.H.P. joints and carcass compositions agree well with those recorded in the earlier study. For sheep of 18 months Masai joints, though heavier, have similar proportional compositions to those found for local long-tailed sheep, except that the Masai thorax is somewhat more fatty. Up to 1½ years old, local long-tailed and Masai sheep have less fatty carcasses than grade B.H.P., a fact which agrees with the practical observation that B.H.P. grades can be killed at a younger age and smaller weights than local sheep because of their ability to lay down subcutaneous fat earlier.

If in a local sheep the very fat tail is considered apart from the carcass, findings are similar to those recorded by Hammond for improved sheep, namely, the thorax contains most fat in lean animals but the loin has the highest percentage in fat sheep. Hammond's data indicate that the neck contains less fat than other joints in British mutton sheep,

TABLE 3. *Proportional Distribution of Muscle, Fat, and Bone in the Joints*

Breed		*Grade Black-headed Persian*								*Masai*					
Age in months		*6*	*8*	*10*	*12*	*14*	*16*	*18*	*28*	*12*	*14*	*16*	*18*	*20*	*28*
No. of animals		*2*	*2*	*1*	*2*	*1*	*2*	*1*	*4*	*1*	*1*	*1*	*1*	*1*	*1*
Neck	Muscle	56·3	56·7	56·0	52·3	57·3	53·4	49·9	43·2	52·9	53·1	56·0	54·3	56·7	33·4
	Fat	10·7	18·7	23·0	23·8	20·2	26·4	34·6	43·4	18·5	25·1	20·9	26·0	22·8	56·0
	Bone	14·3	12·1	10·4	10·8	11·2	9·3	7·5	6·9	15·6	11·5	12·9	10·6	10·3	5·7
	Tendon and waste	18·2	12·1	9·6	12·5	11·9	9·8	7·0	5·9	12·4	9·2	9·8	8·9	9·9	4·5
	Loss	0·5	0·4	1·0	0·6	0·4	1·1	1·0	0·6	0·6	0·4	0·4	0·3	0·2	0·4
Shoulders	Muscle	58·7	57·8	57·9	52·8	56·4	57·0	56·2	55·8	65·0	60·6	62·2	61·1	61·2	43·3
	Fat	9·0	14·6	21·6	23·0	20·6	24·0	26·1	29·4	13·6	15·5	16·6	15·9	18·9	40·2
	Bone	19·4	18·4	14·9	17·2	15·4	12·8	11·6	9·9	19·1	17·4	15·7	17·2	14·9	11·9
	Tendon and waste	12·7	9·9	5·3	6·7	7·3	5·7	5·6	4·1	2·1	6·2	5·6	5·5	4·8	4·2
	Loss	0·2	0·3	0·3	0·3	0·3	0·4	0·5	0·7	0·2	0·3	0·3	0·2	0·2	0·4
Thorax	Muscle	52·8	52·2	55·2	54·3	52·1	45·9	40·2	33·1	46·1	48·4	52·7	50·3	47·9	28·8
	Fat	15·9	21·1	24·6	23·7	24·3	35·2	43·1	55·3	22·2	26·1	26·5	31·1	34·5	59·1
	Bone	14·8	12·9	13·3	12·9	11·6	10·8	9·3	6·8	22·9	16·0	12·7	11·0	11·3	7·6
	Tendon and waste	15·4	13·1	6·4	8·8	12·0	7·9	7·1	4·4	7·8	9·3	7·9	7·3	6·2	4·1
	Loss	1·1	0·6	0·5	0·3	0·0	0·2	0·3	0·4	0·4	0·2	0·2	0·3	0·1	0·4
Loin	Muscle	60·5	63·8	65·7	64·3	61·0	48·2	43·5	34·1	59·8	54·9	57·2	56·0	51·5	20·2
	Fat	13·4	14·8	20·5	21·5	28·0	41·7	47·5	60·0	22·8	31·1	31·7	31·0	37·7	64·4
	Bone	13·4	9·5	6·8	8·4	6·4	6·2	5·4	3·6	11·3	9·1	7·2	8·7	7·5	3·9
	Tendon and waste	12·4	9·5	6·6	5·0	4·5	3·7	3·5	2·1	5·7	4·7	5·8	4·0	3·1	2·1
	Loss	0·3	0·4	0·4	0·8	0·1	0·2	0·1	0·2	0·4	0·2	0·1	0·3	0·2	0·4
Legs	Muscle	60·9	62·8	65·3	63·6	64·0	57·2	53·5	48·2	65·2	62·0	64·2	59·3	62·9	49·3
	Fat	9·1	11·5	16·2	17·4	15·5	26·6	32·4	39·9	15·6	19·9	17·3	19·7	21·6	38·4
	Bone	19·2	17·2	12·2	13·1	14·0	11·1	10·1	8·6	14·3	13·8	14·3	16·2	12·5	9·6
	Tendon and waste	10·6	8·4	6·0	5·7	6·2	4·7	3·3	3·1	4·7	4·2	4·	4·6	2·8	2·5
	Loss	0·2	0·1	0·3	0·2	0·3	0·4	0·7	0·2	0·2	0·1	0·2	0·2	0·2	0·2
Tail	Muscle	15·1	11·6	3·4	5·9	2·5	2·5	2·1	2·0	2·8	3·1	5·4	3·9	4·1	0·7
	Fat	64·2	80·7	94·3	86·3	95·3	94·8	95·9	96·4	90·9	92·4	89·8	93·1	93·1	98·6
	Bone	5·7	1·4	0·6	1·9	0·4	0·6	0·5	0·4	2·1	1·6	1·7	1·1	0·9	0·3
	Tendon and waste	11·3	5·3	1·4	3·8	1·5	1·4	1·2	0·9	3·5	1·7	2·3	1·6	1·6	0·3
	Loss	3·7	1·0	0·3	2·1	0·3	0·7	0·3	0·3	0·7	1·2	0·8	0·3	0·3	0·1
Carcass minus kidneys and kidney fat	Muscle	57·1	57·1	56·2	56·4	53·8	48·4	45·2	38·4	58·0	54·3	56·5	52·6	53·9	33·1
	Fat	12·4	18·3	26·2	23·5	28·1	36·1	41·1	51·3	19·8	25·6	25·4	29·2	30·0	56·6
	Bone	16·6	14·2	11·1	12·5	10·7	9·5	8·4	6·5	16·3	13·6	12·3	12·3	11·2	7·0
	Tendon and waste	13·3	10·0	6·1	7·2	7·2	5·6	4·8	3·4	5·6	6·2	5·6	5·6	4·7	3·0
	Loss	0·6	0·4	0·4	0·4	0·2	0·4	0·5	0·4	0·3	0·3	0·2	0·3	0·2	0·3

but this is not true of fat-tailed or fat-rumped types, where either the shoulders or legs contain the least fat. The quantity of fat in any joint naturally affects the muscle percentage in an inverse manner. Table 3 shows that the muscle percentages in fat-tailed sheep are very different from those of mutton breeds. In unfattened local sheep of less than 12 months the loin has the highest proportion of muscle, very closely followed by the legs and then by the shoulders, neck, and thorax. After 1 year old fat deposits affect the proportions so that, by 1½ years of age, the order for muscle percentage is leg or shoulder, loin or neck, and thorax. The bone proportions are also very greatly affected by fattening, but the order of decreasing bone percentages in the joints is shoulder, leg, thorax, neck, and loin, and this holds for unfattened lambs and grossly over-fattened adults. In improved mutton sheep the greatest proportion of bone is in the thorax in unfattened animals and in the neck of fattened adults. The fact that the shoulders and legs contain the highest proportions of bone in fat-tailed sheep, irrespective of age or degree of fattening, is merely a further confirmation of the practical butcher's observation that these animals have poorly fleshed, long limbs that are badly in need of improvement from a mutton point of view.

If the muscle and fat are expressed as a percentage of the bone in each joint, Hammond found for British sheep that the joints took the following order for descending muscle proportions: loin, leg, neck, and then shoulder and thorax. In local fat-tailed sheep the loin has always the highest muscle : bone ratio with usually the neck second, then the order becomes more variable. The order of the joints in British as well as local sheep for fat : bone ratio varies with the degree of fatness. Whereas in fat British sheep the loin shows the highest and the neck the smallest proportions, in fat-tailed sheep the neck or thorax comes second to the loin in fat : bone ratio, with the leg and shoulder ratios much smaller. If the tail is considered, some extremely high fat : bone ratios are found in fat-tailed sheep.

Owing to the fine, light-boned nature of B.H.P. sheep the ratios muscle : bone and fat : bone are higher than for Masai sheep, indicating that B.H.P. joints contain a higher proportion of edible meat. Long-tailed local sheep have bones almost as light as B.H.P., but the ratios of muscle and fat to bone are more similar to those of Masai sheep. Therefore, judged on the weight of the joints, B.H.P. grades give a higher proportion of edible meat than indigenous sheep, and this emphasizes the importance of keeping skeletal weights as low as possible. On the other hand, B.H.P. joints contain a higher proportion of fat than those from native sheep but, since joints of indigenous sheep already carry excessive subcutaneous deposits, the B.H.P. grades are even more wasteful of fat. To suit European tastes adult B.H.P. joints have to be trimmed of large quantities of fat, and this surplus can have value only as a poor quality soft suet.

When considering the fat : bone and muscle : bone ratios of British sheep, Hammond found that there was very little difference in the proportions of muscle to bone in adult semi-wild or improved mutton

animals. On the other hand, large differences occurred in the fat : bone ratios, and the increase of fat was shown to be the main change in composition resulting from breed improvement. Adult local sheep have muscle : bone ratios well within the range recorded by Hammond for British breeds, but fat : bone proportions are very much higher. The problem of improving semi-wild British breeds is to increase the amount of fat in the carcass, but that of improving local sheep is to reduce fat considerably, particularly the excessively wasteful subcutaneous deposits on the loin and rump and in the tail.

Hammond found the age-changes in the muscle : bone ratio of British sheep to be (*a*) rapid growth from birth to 5 months, (*b*) slower growth till about 11 months of age, and (*c*) very slow growth which soon ceases after the animals become 1 year old. In the present work the early phase could not be studied, but from about the age of 16 months local sheep make relatively little extra muscular growth. On the other hand, the development of fat reaches its maximum rate at a later age, and the degree of fattening varies with individuals and with management.

In British breeds the percentage of muscle in the carcass always exceeds the percentage of fat, but it was shown in the earlier study [2] that the reverse holds true for fattened B.H.P., whilst in fattened long-tailed native sheep, muscle and fat proportions are about equal. The present data confirm the previous observation on B.H.P., and show that gross over-fattening of a Masai wether caused the fat to exceed the muscle in the total carcass. The data for local sheep have been recalculated on a carcass-minus-tail basis in Table 4. The figures indicate that, unless over-fattened, Masai sheep have higher muscle proportions at a given age than either the local long-tailed sheep or B.H.P. grades, lower fat proportions, but greater amounts of bone.

Hammond, when discussing British sheep, said, 'Since the separation of muscles from fat involves considerable work in dissecting out individual muscles and removing the fat between them, it would be a great advantage to obtain an estimate of the amount of fat in the body by sampling one joint only.' He found that the curve of shoulder-fat content approximated closest to the curve of carcass-fat percentage, and that the leg came next, with the neck the least suitable. Owing to the greater accuracy in jointing a leg he chose the leg as being the best sample joint for estimating body-fat content. Pálsson [3] also obtained the same result. For fat-tailed sheep these observations do not hold, and if curves are made of the data from this study it is seen that the fat-content of the carcass-minus-tail is most closely represented by the proportions in the neck. The curves for loin and thorax fat lie above and those of the legs and shoulders lie below the curve for the carcass-minus-tail.

In British breeds the omental and kidney fats form the two largest deposits of fat, and though the amounts of subcutaneous fat may form a higher percentage of the empty live-weight, it is spread over the carcass. In fat-tailed and fat-rumped sheep the largest accumulation of fat occurs in the tail or on the rump, with the omental and kidney

TABLE 4. *Muscle and Fat in the Carcass and Joints expressed as Percentage of the Bone Weight*

Breed	*Age in months*	*No. of sheep*	*As % of bone*	*Carcass*	*Neck*	*Shoulder*	*Thorax*	*Loin*	*Leg*	*Tail*
Grade Black-headed Persians	6	2	Muscle	344	394	303	357	451	317	265
			Fat	75	75	46	107	100	48	1126
	8	2	Muscle	402	468	314	405	693	365	829
			Fat	129	154	79	163	156	67	5764
	10	1	Muscle	506	538	388	415	966	535	567
			Fat	236	221	145	185	301	133	15717
	12	2	Muscle	451	484	307	421	765	485	310
			Fat	188	220	134	184	256	132	4544
	14	1	Muscle	503	511	431	469	953	457	625
			Fat	263	180	69	209	437	111	23950
	16	2	Muscle	509	574	445	425	777	515	416
			Fat	380	284	187	326	673	240	15800
	18	1	Muscle	538	665	484	432	805	530	420
			Fat	489	461	225	463	879	320	19180
	28	4	Muscle	591	626	564	487	945	560	500
			Fat	789	629	297	813	1665	464	24100
Masai	12	1	Muscle	350	339	340	204	529	456	133
			Fat	121	119	71	97	202	109	4328
	14	1	Muscle	400	462	348	302	603	449	194
			Fat	188	218	89	163	342	144	5775
	16	1	Muscle	459	434	396	415	794	449	318
			Fat	207	162	103	209	356	121	5282
	18	1	Muscle	428	512	355	457	643	366	354
			Fat	237	245	92	282	356	121	8465
	20	1	Muscle	481	550	411	424	687	503	455
			Fat	268	221	127	305	503	173	10344
	28	1	Muscle	473	586	364	379	749	514	233
			Fat	809	982	338	778	1651	400	32867

deposits coming next. This order holds even for immature lambs 6 months old, in which fat deposition has hardly started. As has been stated above, these large subcutaneous fat deposits, which are so wasteful, detract considerably from the mutton potentialities of local sheep. Hammond states that 'A moderately thick and even covering of subcutaneous fat is valuable in that it prevents the hardening and drying of the muscle both before and during cooking, but thick layers are wasteful and have only a suet value'. In local sheep tremendous fat deposits in the tail and on the rump occur before the shoulder muscles are properly covered, and if the sheep are killed before the rump and tail fats become excessive, the legs and shoulders dry out and shrink on cooking. Further, there is comparatively little intra-muscular fat in the limb muscles of fat-tailed sheep, though the shoulders, but not the legs, can contain much intra-muscular fat. The latter type of fat is admittedly of value in improving the quality of mutton but, with their lack of subcutaneous fat and their long thin, rather than short blocky, muscles, the shoulders and legs of fat-tailed sheep lose more during cooking than corresponding joints from mutton breeds, and are considerably less tender. The poor mutton qualities of the legs and shoulders and the excessively wasteful rump and tail fats are the main points needing attention if our local sheep are to become improved producers of mutton. The data obtained show conclusively that the introduction of B.H.P.

blood has in no way improved this state of affairs but has tended to increase the amount of fat in the carcass.

Not only does the amount of fat deposited vary in the different regions of the body but the nature of the fat also varies. The iodine values of fat from various parts were determined in 16 of the sheep dissected in this study and the average values were: kidney fat 31·89, omental fat 32·78, sternum (inner fat layers) 44·83, sternum (outer fat layers) 50·87, tail fat 48·74. The subcutaneous fat was thus much softer and less saturated than the internal deposits.

TABLE 5. *Percentages of Muscle, Fat, and Bone in 'Carcass-minus-Tail'*

Breed	*Age*	*Muscle*	*Fat*	*Bone*
Black-headed Persian	6 months	57·7	11·6	16·7
	8 ,,	58·9	15·7	14·8
	10 ,,	60·4	20·7	12·0
	12 ,,	58·2	21·3	12·9
	14 ,,	60·3	19·5	12·0
	16 ,,	52·5	30·9	10·3
	18 ,,	48·4	37·0	9·0
	28 ,,	41·6	46·8	7·1
Masai	12 ,,	58·5	17·8	16·7
	14 ,,	56·5	22·8	14·1
	16 ,,	59·0	22·2	12·8
	18 ,,	56·2	24·5	13·1
	20 ,,	56·3	27·0	11·6
	28 ,,	36·7	51·7	7·7

Discussion

Although fat-tailed sheep differ considerably in size, conformation, and rate of development from improved mutton breeds, they nevertheless show similar age-changes in the development of the different regions of their bodies. Owing to their large fat deposits, fat-tailed sheep yield carcass percentages as high as those of improved and higher than those of semi-wild British breeds. As a probable adaptation to their nutritional environment the alimentary tract forms a high proportion of the empty live-weight.

The carcass weight is distributed between the joints so that the early maturing joints have proportions similar to those of unimproved breeds and the later maturing ones have proportions similar to those of improved breeds. The latter resemblance is due to excessive subcutaneous-fat deposits and not to equality in development. The compositions of the joints in local sheep differ from those of British breeds, and whereas Hammond found that the shoulder gave the best measure of carcass fat in British sheep, the neck is the most representative joint in local sheep. Local sheep carcasses also contain much more fat than British breeds, though their muscle : bone ratios are well within the range found by Hammond. This extra fat is deposited in large subcutaneous masses which have little except suet value. Intra-muscular fat is lacking and joints, such as the leg and shoulder, dry out badly on cooking. The

limb joints are relatively too long and too small, and their muscles are long and thin instead of being short and blocky as in improved mutton animals.

Improvement of semi-wild British breeds means increasing the amount of fat in the carcass, but improvement in the mutton capabilities of fat-tailed sheep means reducing its quantity, particularly the subcutaneous deposits, and increasing the relative size and conformation of the limb joints.

From the data collected there is obviously little difference between the local types, and their mutton quality is not enhanced by crossing them with Black-headed Persians. The Persian crosses, owing to their relatively smaller proportions of bone, yield joints with a higher proportion of eatable meat than the indigenous types, but they also contain increased proportions of fat. Since the fat-content of adult native sheep is already too high, the result is not an improvement in mutton quality. The only good effect of introducing B.H.P. blood into local sheep is a direct result of their more fatty carcasses, because it allows cross-breed sheep to be killed at an earlier age but smaller weight than indigenous sheep. The quality of these younger carcasses is, when judged on a muscle : fat : bone basis, no better than that of long-tailed native sheep, though the former will probably be more tender owing to the younger age of slaughter. Masai are larger than long-tailed sheep but are ready for slaughter at the same age and give mutton of similar quality though with a slightly higher muscle percentage.

It appears, therefore, that indigenous fat-tailed sheep make poor-quality mutton when judged by European standards, and that the quality will not be improved by crossing local types either amongst themselves or with other imported fat-tailed or fat-rumped sheep. Crossing may affect the age at which enough fat has been deposited to justify slaughter, but it will not improve the limb proportions nor reduce the wasteful fat deposits.

In the earlier study [2] methods of improving the quality of fat-tailed sheep were discussed, and it was suggested that the best way would be to cross them with small, good mutton-quality and hardy British rams. I still believe this to be the best method, and I suggested that probably a breed like the Welsh Mountain would best fit into our environment.

Black Welsh Mountain rams have been imported and crossed with local types, but the results have been very disappointing. There has been heavy lamb mortality, possibly because the native ewes had insufficient milk to feed their quicker growing offspring satisfactorily. Bottle-feeding allowed other lambs to grow much more satisfactorily but, at the moment, the half-grade ewes in the flock show little improvement in their general appearance on the indigenous sheep: their legs and shoulders are no better than local type, but there is an absence of wasteful subcutaneous fat deposits. The reason for the failure of the half-grade Welsh sheep is not immediately obvious but, since Mpwapwa conditions are not suited even to local sheep, it is possible that better results would be obtained in better sheep country. There are the further possibilities that the Welsh (like the Ayrshire) is less suited to tropical

conditions than other breeds, or that the upper level of Welsh blood, compatible with a healthy existence in the local environment, is less than that in the half-bred. Constitutional failures occur in cattle once they are too highly graded, even when the nutritional level is on a much higher plane than was provided for these sheep, and it is possible that, unless we can improve the environmental conditions appreciably, only a very small amount of grading will be possible with sheep. The fat-tailed sheep is the result of centuries of adaptation to local environments and must be accepted as the best type for the existing conditions, and obviously grade European sheep will be out of harmony with that environment.

Unless we can first improve the local conditions so that fat-tailed sheep will thrive and excel, it is unlikely that success will follow crossing with European sires. It is expecting too much of half-grade British animals to ask them to develop their possibly superior mutton qualities in an environment which is sub-optimal for types adapted to life in semi-arid regions.

Summary

Data are presented confirming the poor mutton quality of the carcasses of indigenous fat-tailed sheep. Attempts to improve this quality must increase the proportions of leg and shoulder joints in the total carcass and reduce the excessive subcutaneous fat deposits.

Neither the crossing of local breeds amongst themselves nor with other imported fat-tailed breeds will improve mutton quality. Crossing with Black-headed Persians increases the proportion of fat in the carcass so that the age of slaughter becomes less than for indigenous types. Adult Black-headed Persian crosses yield poorer quality carcasses than local sheep.

Observations are made on an attempt to improve local sheep by crossing them with Black Welsh Mountain rams.

REFERENCES

1. J. HAMMOND, Growth and Development of Mutton Qualities in Sheep, 1932.
2. M. H. FRENCH, Empire J. Expt. Agric., 1938, **6.** 112.
3. H. PÁLSSON, J. Agric. Sci., 1939, **29.** 544, and ibid., 1940, **40.** 1.

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CANADIAN RESEARCH ON MALTING BARLEY[1]

PART I. MALTING TESTS AND QUALITIES

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WITH PLATE II

Introduction.—Investigations of malting barleys grown in Canada began in 1926 when T. J. Harrison, then Professor of Agronomy at the University of Manitoba, devised laboratory equipment for the simultaneous malting of some small samples of barley. Unpublished reports show that he envisaged his investigations as applied research; his object was to develop a laboratory test that could be used to help plant-breeders and agronomists improve Canadian malting barleys. This conception has dominated Canadian research on malting qualities up to the present time.

Malting quality in barley is not easy to define. It depends on the malting method and the brewing process in use, and on the type of beer required. These differ from one country to another, and even within the same country, so that no single definition of malting quality can be widely accepted. It appears that in each country a system of malting and brewing has developed that is well adapted to the type of barley grown there. Broadly speaking, when the raw materials and the processing methods have been standardized, the end-product also becomes standardized, and when the consumer acquires a taste for this product an equilibrium is set up which many interests strive to maintain.

Processes used in Canadian malting and brewing industries are adjusted to make best use of parcels of the variety O.A.C. 21 grown in Canada under environmental conditions that produce barley having a protein-content equal to or slightly lower than the Canadian average. When the Canada Grain Act was revised in 1929, the barley grades were changed, and, on recommendations made by Canadian maltsters, official recognition was given to O.A.C. 21 by requiring that only varieties equal in malting quality to this standard variety should be permitted to enter the upper grades of malting barley. It follows that any variety that is closely similar in malting characteristics to O.A.C. 21 has been accepted by Canadian maltsters, whereas any variety that is inferior to O.A.C. 21 in any important barley, malting, or malt property has been considered unsatisfactory. This condition had a fundamental effect on barley investigations.

First, it provided initial criteria for judging the malting quality of any new variety: the new and standard varieties could be grown side by side under a representative range of environmental conditions so as to produce representative samples of each, and these could be compared to determine whether the new variety was 'equal for malting purposes to O.A.C. 21' as required by the Canada Grain Act. This required the develop-

[1] Published as paper No. 67 of the Grain Research Laboratory, and as paper No. 228 of the Associate Committee on Grain Research (Canada).

ment of standard equipment and methods for testing the barley; the progress that has been made is described in the first two sections of this paper.

A second phase of the investigations also stems from the early acceptance of O.A.C. 21 as a standard. It involved a study of O.A.C. 21 with the object of tabulating its malting properties, and the more difficult task of attempting to determine whether these merit its adoption as a permanent standard. This work has been hampered by lack of facilities for experimental brewing, but the building of these in government laboratories did not seem feasible. Nevertheless, since O.A.C. 21 has been used in all investigations made in Canada for the past decade or more, there is now available an extensive body of data on this variety. And it may be said at once that the writer and his colleagues have not as yet found grounds for believing that O.A.C. 21 is anything but an extremely satisfactory standard. Much of the evidence on which this opinion is based is summarized in the third section of this paper.

Comprehensive studies have been made of the relations that exist between various barley and malt properties, and these are described in the fourth section. This work was undertaken partly to elucidate the factors that control malting quality, and partly to develop more rapid methods of assessing the comparative merits of the new hybrids produced in such large numbers by plant-breeders. Some progress has been made towards both goals. The final section of the paper summarizes the direct assistance that Canadian malting chemists have given to their colleagues in the fields of plant-breeding and agronomy.

Laboratory Malting Equipment

The first equipment was designed at the University of Manitoba in 1926 and was described by Harrison and Rowland [1]. It consisted of a steep-tank, for twelve 500-gm. samples, continuously fed with cold water from a supply tank equipped with cooling-unit and temperature-control; a germination unit in which air was blown through a spray, cooled by passing it through coils immersed in a controlled water-bath, and then fed into a germination chamber holding 24 stationary malt cages; and a kiln in which 12 cages were attached to a rotating wheel, the air being blown first through a thermostatically controlled heating chamber and subsequently past the malt cages.

About 1934 three malt laboratories were established in the U.S.A., at the Universities of Wisconsin [2] and Minnesota [3] and in the Department of Agriculture, Washington [4]. But only the first of these has been continuously active since it was established.

In 1937 the writer [5] described equipment built for the National Research Laboratories, Ottawa. It consisted of twin units with two steep-tanks, two germinators, and two kilns, and was designed to provide flexibility for investigations of malting methods. The steep-tanks were similar to the original Manitoba model, but they proved unsatisfactory and were later replaced with a new model (described below) incorporating certain automatic features. Each of the germination chambers was equipped with a separate air-conditioning unit, and the cooling load was reduced by recirculating a large proportion of the air; moreover, pro-

vision was also made for continuous rotation of the samples to prevent matting. The kilns were similar to the Manitoba model, but a recirculation of part of the air was used to reduce the power consumption.

In 1937 the germinator at the University of Manitoba was modified,

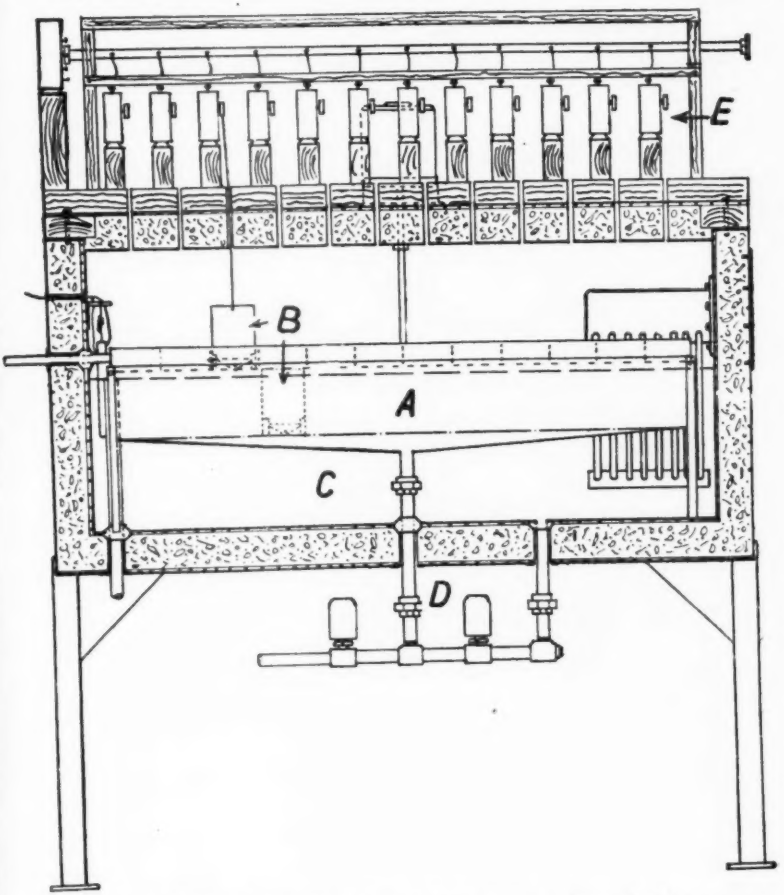

FIG. 1. Laboratory steep-tank for 24 barley samples, front elevation.

and a new steep-tank and kiln were built [6]. The steep-tank was replaced in 1940 by a new model [7] based on the design developed at Ottawa, and a little later a new germinator incorporating the best features of both the Manitoba and Ottawa units was also installed [8]. Because of the man-power shortage, operation of the malting laboratory at the University of Manitoba was discontinued in 1941, and the equipment was transferred to the writer's laboratory. There follows a brief description of the equipment and methods now in use.

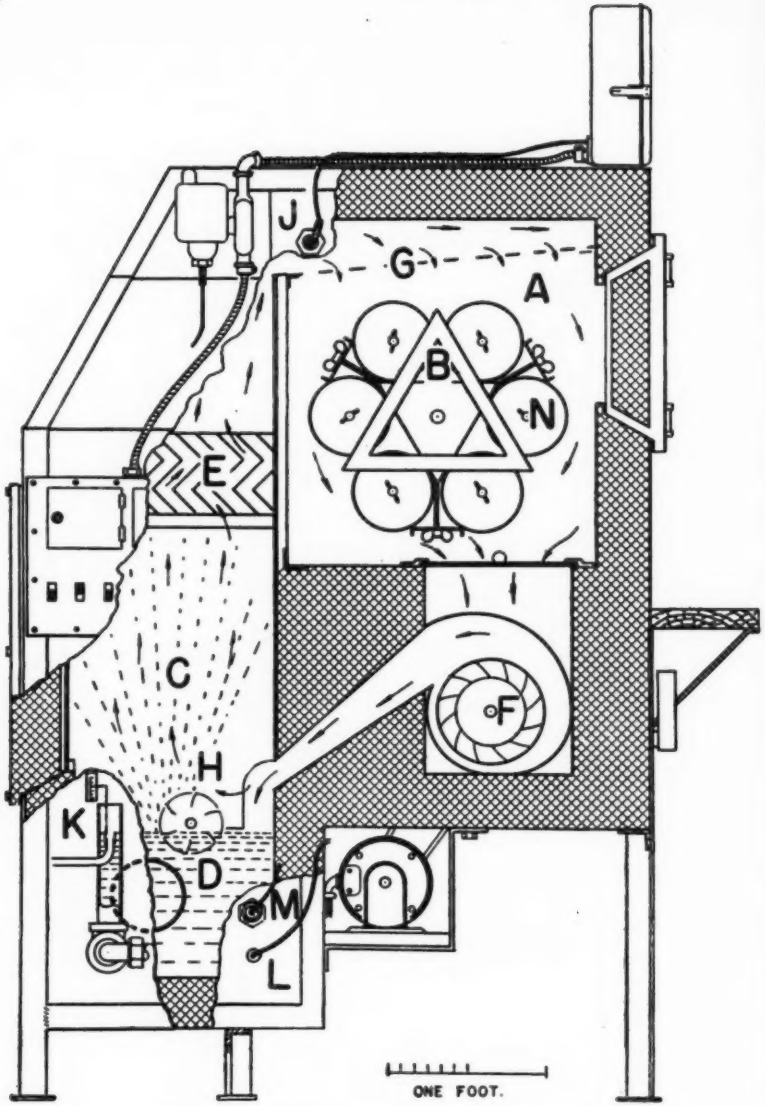

FIG. 2. Laboratory germination chamber for 24 samples, side view.

Steep-tank.—A drawing of the front elevation of the steep-tank [7] is shown in Fig. 1. The samples are steeped in a long narrow tank *A* holding 24 cages *B*. It is immersed in a larger thermostatically controlled

water-tank *C*, and is connected to this and to waste by means of pipes *D* fitted with solenoid valves operated by an electric time-switch. This mechanism permits the inner tank to be drained and refilled automatically. A second automatic feature, consisting of a battery of alarm clocks *E*, makes it possible to drop samples into the steep-tank at predetermined times. This feature is required because all barleys are steeped to the same moisture-content and must be taken out of the steep at the same time; but different barleys require different steeping periods (determined in pilot tests) and must therefore be put into the tank at different times.

Germination unit.—A photograph of the germination chamber is shown in Plate 11 (part of the steep-tank can be seen at the left and part of the

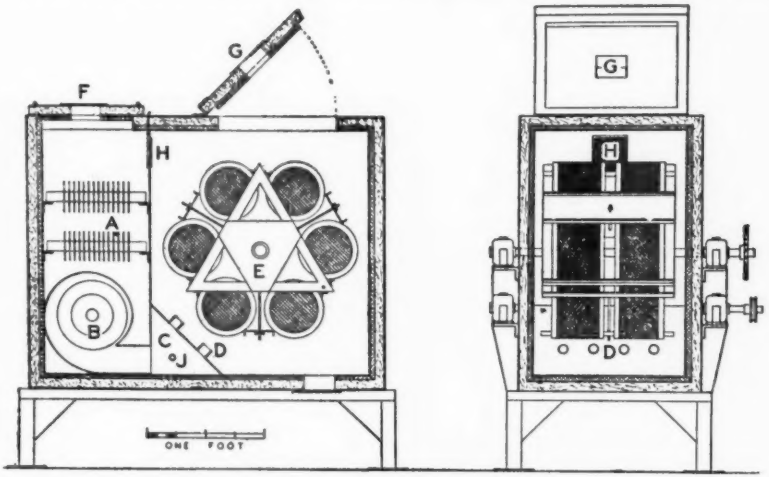

FIG. 3. Laboratory kiln for 12 samples, side and front elevations.

kiln on the right) and a drawing of the side elevation is shown in Fig. 2. The unit consists of a germination chamber *A* holding 24 cylindrical malt cages *N*, attached to a rotating frame *B*. Air is circulated continuously through the germination chamber and a spray chamber *C* by means of a fan *F*. The spray is created by a rotor with notched disks *H* running in a water-bath *D*, which is cooled by means of a small refrigeration-unit. The bulb *J* of the thermo-regulator is placed in the germination chamber, and serves to maintain the temperature of the spray by controlling the refrigerator-motor. As the unit is insulated with 4 in. of cork, and as the air circulates rapidly, there is little increase in air-temperature between the spray and germination chambers; the relative humidity of the air is therefore close to 100 per cent. A paper by Meredith, Hlynka, and Sallans [8] containing a more detailed description of this equipment is in the press.

The kiln.—A description of the kiln now in use has been published by Anderson and Rowland [6]. Drawings showing side and end elevations appear in Fig. 3. The vertical heating chamber is located at the back of

the kiln and contains six 100-watt fin-strip heating elements *A*. A centrifugal fan *B* draws air past the heating elements and blows it into the air-distribution chamber *C*, from which it is directed at the malts by eight 1-in. pipes *D*. The drying chamber contains a revolving framework *E*, which holds 12 samples of malt contained in cylindrical wire-mesh cages. An air-inlet *F* and an outlet *G* are provided in the heating chamber and the lid of the drying chamber respectively, and an air-vent *H* permits air to be returned from the drying to the heating chamber. The temperature in the drying chamber is controlled by means of a time-temperature controller, with bulb at *J*.

Methods.—Samples equivalent to 250 gm. of barley dry-matter are steeped to 44 per cent. moisture-content at 50° F. with a change of water and a 1-hour aeration period after each 11 hours; steeping requires 2½ to 3½ days, depending on the sample. The samples are then transferred to cylindrical cans with fifty ⅛-in. holes, and these are attached to the revolving frame in the germination chamber, which is operated at 53° F. The cages are revolved (3 rev. per hr.) for 12 hours out of each 24, and water is added at the end of 3 days to bring the moisture-content to 46 per cent. Germination is complete in 6 days. The samples are transferred to wire-mesh cages and rotated at 1 r.p.m. in the kiln. The kilning schedule is as follows: 0–6 hrs., continuous rise in temperature from 85° to 120° F.; 6–22 hrs. at 120° F.; 22–30 hrs., continuous rise from 120° to 150° F.; 30–40 hrs. at 150° F.; 40–42 hrs., continuous rise from 150° to 175° F.; and 42–48 hrs. at 175° F. When the sample is removed from the kiln it is kneaded in a small bag for 1 minute; the roots which are rubbed off in this process are removed by sifting; and the malt yield is calculated from the weight of the polished malt.

Since 1936 the official method of the American Society of Brewing Chemists has been used in Canada for determining malt extract; it is essentially the European Congress method. Saccharifying activity has been determined by a modified Lintner procedure [9, 10] involving the use of a ferricyanide reagent instead of Fehling's solution. An autolytic method for determining the proteolytic activity of malt was developed by Ayre and Anderson [11], and Meredith and Sallans [12] have contributed to the development of methods for studying wort properties. For the wide range of other barley and malt properties studied in

TABLE 1. *Standard Errors for the means of Duplicate Analyses and Duplicate Malting Tests made in the same and different batches*

Determination	*Duplicate analyses*	*Duplicate malting tests*	
		In same batch	*In different batches*
Extract, %	0·07	0·082	0·093
Moisture, %	0·038	0·037	0·045
Colour, Lovibond units	0·049	0·043	0·049
Saccharifying activity, °L.	0·80	0·99	2·77
Permanently soluble nitrogen as % of wort solids	0·016	0·011	0·024
Malting loss, %	..	0·065	0·292
Sprouts, %	..	0·058	0·179

Canada, methods have been borrowed with minor variations from earlier workers.

Precision.—The precision of the laboratory malting test and the possible effects on it of uncontrollable variations in the equipment have been investigated from time to time [6, 8, 13]. The most comprehensive study was made of the original equipment installed in the National Research Laboratories, and data given by Anderson and Meredith [13] are shown in Table 1.

Factors that Limit the Utility of the Malting Test

The precision of malting and analysis attained in the malting test is adequate for all practical purposes, and laboratory errors are not a limiting factor in the study of varietal differences in the malting quality of barley. In the writer's opinion the limiting factors are the differential effect of environment on varieties and the differential effect of malting method on varieties. Both these effects have been studied.

Differential effect of environment.—When a series of varieties is grown at a number of stations representing a range of environmental conditions, the varieties do not rank in the same order at each station with respect to various barley and malt properties; though a variety *A* may be better than a variety *B* in one environment, the order may be reversed in another. When a variety is licensed for distribution in western Canada it may be grown over a large area representing a wide range of conditions, and the average performance of the test and standard varieties over the whole area must be examined. This involves growing the varieties in properly replicated plots at representative stations. By analysing the variance of the data it is possible to determine whether the difference between a given pair of varieties is statistically significant. The spread between varietal means that cannot be considered statistically significant in an investigation of a practical size sets a limit to the ability to distinguish between varieties. It is difficult to generalize, since this spread will vary from one investigation to another in accordance with the varieties and stations studied, but experience with many tests extending over many years indicates that it is of the order of 1 per cent. for malt extract and 10 per cent. for saccharifying activity and wort nitrogen.

Differential effect of malting methods.—The malting method has also a differential effect on varieties. If a number of varieties are malted by several different methods, the rank order of the varieties will not be exactly the same for each method. This raises the questions of what method should be selected as a standard for testing varieties, and of how much reliance can be placed on the results of a single method. These matters have been investigated to obtain information on the relative magnitudes of the differential effects of environment and method on varieties.

Fig. 4, taken from a paper by Anderson and Sallans [14], illustrates principally the effect of increasing germination time on the properties of malts made from O.A.C. 21 and Wisconsin 38 grown at Nappan, Nova Scotia, and Indian Head, Saskatchewan. It will be observed that the spread in extract between these varieties when grown at either Indian

Head or Nappan decreases with increasing germination time; and that a similar decrease in the spread for diastatic power occurs with increasing germination time for samples grown at Indian Head, whereas this effect is not apparent for samples grown at Nappan. It is thus clear that the quantitative evaluation of the two varieties would not be the same for malts made under different germination conditions.

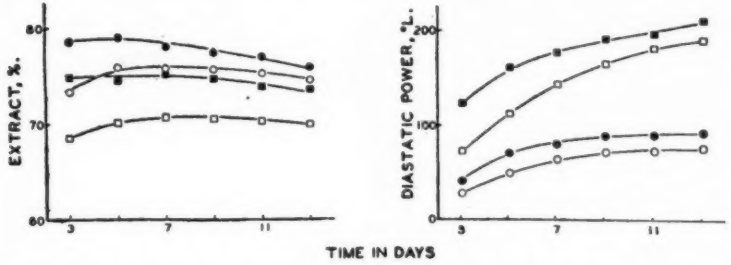

FIG. 4. Effect of germination time on malt quality: ● O.A.C. 21 from Nappan; ○ Wisconsin 38 from Nappan; ■ O.A.C. 21 from Indian Head; □ Wisconsin 38 from Indian Head.

Comparison of differential effects.—Results obtained in a study [15] involving 4 varieties, 4 stations, and 4 malting methods (combinations of temperatures of 50° and 56° F., and of moisture-contents of 42 and 44 per cent.), are illustrated for wort nitrogen in Fig. 5 by means of a family of 25 histograms. These are arranged in tabular form; the columns show the results for different malting treatments and the means over all treatments, and the rows show the results for samples from different stations and the means over all stations. Each individual histogram contains 4 columns, which represent 4 varieties: Olli, O.A.C. 21, Hannchen, and Regal—from left to right. The hatched portions of each column represent the results for 6-day malts and the white portions represent the additional effects of growing the malts for three more days.

By considering the columns of histograms, especially the five in the last column, the extent to which the varieties fail to fall in the same order at each station can be determined; and by considering the rows of histograms, especially those in the bottom row, the extent to which the varieties fail to fall in the same order under each malting treatment can be assessed. A general comparison of the differences in configurations of histograms within and between rows leaves little doubt that the differences between rows are greater, and thus that the differential effect of environment on varieties is appreciably larger than the differential effect of malting treatments on varieties.

Both the papers cited contain additional data concerning other malt properties, and further studies of the comparative magnitudes of the differential effects of environment and malting method on varieties have also been made by Anderson and Meredith [16, 17]. As a result of these studies it is concluded that the former effect is the limiting factor in studies of the comparative malting qualities of varieties. It is clear,

however, that the spreads between certain pairs of varieties can be affected by changing the malting conditions. But if wide differences are shown to exist between any pair of varieties under one set of malting conditions, it appears that these will persist under all sets of conditions

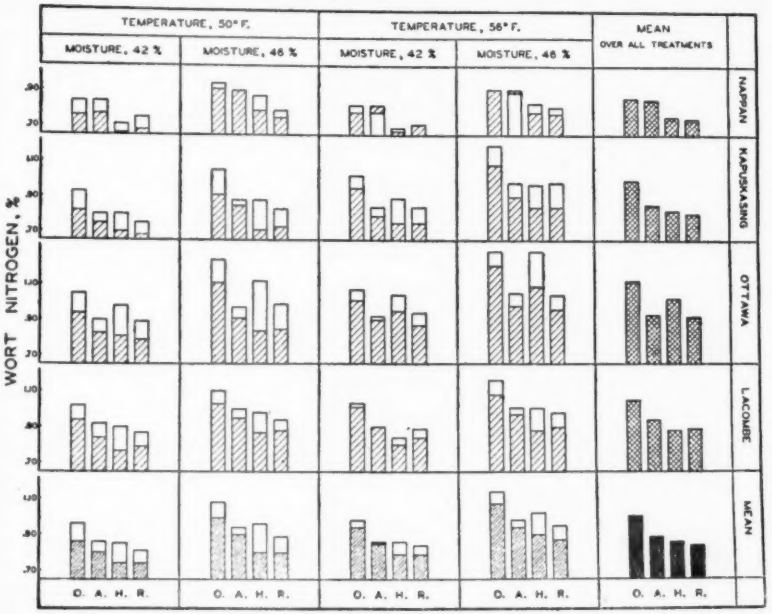

FIG. 5. Histograms for wort nitrogen illustrating the differential effect of stations and malting treatments on varieties. The four columns in each histogram represent four varieties: O = Olli, A = O.A.C. 21, H = Hannchen, and R = Regal. Tops of hatched portions represent six-day malts, and tops of blank portions represent nine-day malts.

within a reasonable range. In general, it is believed that if a standard malting test that simulates conditions in commercial plants shows that on the average a variety differs from the standard by more than 1 per cent. in extract or 10 per cent. in other properties—such as saccharifying activity and wort nitrogen—it will be found that a real difference exists between the varieties, which cannot be overcome by any reasonable change in malting conditions. The routine malting test made by a standard method thus serves to eliminate varieties that are inferior to the standard with respect to one or more important malt qualities.

Comparative Malting Qualities of O.A.C. 21 and Certain Other Varieties

Data on the barley, malting, malt, and wort properties of 5 varieties are shown in Table 2. All 5 are six-row varieties of the Manchurian type; the first 2 have rough awns and the last 3 represent the newer class of smooth-awned barleys. The data were assembled from a series of papers by the writer and his colleagues [18, and papers cited therein];

reference numbers for each property are given in the second column of the table.

TABLE 2. *Properties of Five Barley Varieties grown in Canada*

Property	*Ref. No.*	*Varieties*				
		O.A.C. 21	*Olli*	*Velvet*	*Wisc. 38*	*Regal*
Barley						
1,000 kernel weight, gm.	36	31·0	29·6	31·1	32·4	31·6
Plump kernels, %	36	74	64	77	86	77
Extract, %	18	75·3	77·2	74·5	74·4	74·3
Starch, %	18	53·6	54·7	52·4	53·2	52·7
Crude cellulose-lignin, %	18	10·5	10·1	11·0	11·3	10·9
Nitrogen, total, %	3	2·24	2·22	2·37	2·40	2·35
—— salt-soluble, %	3	0·77	0·79	0·72	0·66	0·71
—— as hordein, %	3	0·88	0·77	0·94	0·89	0·92
—— as glutelin, %	3	0·58	0·65	0·71	0·69	0·72
Saccharifying activity (papain), °L.	44	225	254	217	188	163
Malting						
Time to steep to 44%, hr.	36	75	55	80	91	86
Malting loss, %	36	7·4	7·7	6·6	6·6	7·0
Sprouts, %	36	2·2	2·1	1·7	1·6	1·7
Malt						
Saccharifying activity, °L.	44	127	153	124	96	85
Starch-liquefying activity	46	419	768	385	281	275
Autolytic diastatic activity	46	785	958	764	664	676
Autolytic proteolytic activity	17	235	291	210	150	196
Index of nitrogen modification	36	36·4	41·2	33·8	28·5	32·0
Extract, %	36	73·9	76·0	72·3	71·2	71·1
Wort						
Nitrogen, %	36	0·82	0·93	0·80	0·64	0·74
Attenuation, %	41	78·2	79·4	77·8	75·7	75·1
Turbidity, initial	41	18	19	32	73	38
—— final	41	130	120	148	238	116
Viscosity	41	1·46	1·44	1·48	1·59	1·49

To have satisfactory malting quality, a barley variety must have kernels of suitable size and shape with a firmly attached hull, it must contain a high proportion of extractable material, and it must be able to produce the enzymes required to make this material soluble during the malting and mashing processes. These are the essential qualities, though there are others that might be mentioned in a more detailed discussion [19].

The data in Table 2 show that Olli is below average and Wisconsin 38[1] is above average for kernel weight and percentage of plump barley (retained by $\frac{5}{64}$-in. ring-grader). In Canada, a 6-day germination period is used in commercial malting plants, and kernels that are too large do not

[1] In the U.S.A. this variety is now called Wisconsin Barbless.

modify adequately in that time. Wisconsin 38 appears to be at a slight disadvantage in this respect. On the other hand, Olli has kernels that are a trifle small and usually fails to yield a high percentage of plump kernels suitable for making malt of the highest grade. Also both Wisconsin and Regal have hulls that are none too firmly attached, and these varieties tend to produce ragged malts.

The extractable material in the barley can be measured directly by a mashing procedure that involves the addition of amylases. On *a priori* grounds the highest extract-yield would be expected from barleys that contain large amounts of their carbohydrates in the form of starch and a high proportion of the more soluble nitrogen fractions. This point is illustrated by the data in Table 2. Olli, which yields most extract, has the highest starch-content and the least amount of crude cellulose and lignin; it also contains the most salt-soluble protein, and less glutelin than all other varieties except O.A.C. 21. Judged by the same criteria, O.A.C. 21 readily holds second place. The other three varieties are all higher in total nitrogen and lower in starch-content than Olli and O.A.C. 21.

The ability to realize the potentially extractable material of the barley in the form of malt extract (wort) depends on enzymes. At present, only one of these can be measured in the barley. This is β-amylase, which can be released by extraction with a papain solution and can be measured by a Lintner method. The saccharifying activity of the malt depends largely on the β-amylase, although α-amylase also contributes; and Sallans and Anderson [20] have demonstrated an inter-varietal relation ($r = 0{\cdot}90$) between the total saccharifying activity (papain) of barley and the saccharifying activity of malt. Table 2 shows that Olli has the highest saccharifying activity; it is followed by O.A.C. 21 and Velvet; Wisconsin and Regal give far lower values.

We should also expect those varieties that are most liberally supplied with enzymes to grow most vigorously during the germination period, and these should therefore show higher malting losses and larger amounts of sprouts. Judged by these criteria, Olli and O.A.C. 21 again rank above the other three varieties in general enzymatic activity.

Data on the enzymatic activities of the malts serve to confirm these conclusions. Saccharifying activity represents largely the β-amylase. Starch-liquefying activity represents the α-amylase, and this enzyme is also chiefly responsible for the autolytic diastatic activity. Proteolytic activity is also measured by an autolytic process, and is reflected to some extent by the index of nitrogen modification, which also depends in part on the percentage of salt-soluble nitrogen in the barley [21]. By all these criteria, Olli is again shown to have the highest enzymatic activity; it is followed by O.A.C. 21, with Velvet only slightly lower. Wisconsin and Regal are obviously deficient in all enzymatic activities.

The effects of these differences, and of those relating to extractable material in the barley, are reflected in the yields of malt extract. Olli, which is best on both counts, gives by far the highest extract yield; O.A.C. 21 is a good second. Velvet stands third because, although it is deficient in extractable material, it is fairly well supplied with enzymes.

It will be observed that for O.A.C. 21 and Olli the difference between barley and malt extracts is about 1·3 per cent.; the corresponding difference for Wisconsin and Regal is 3·2 per cent. This is further evidence of an enzyme deficiency, which when superimposed on lack of extractable material causes a low yield of malt extract.

The interpretation of the data on wort properties is not as easy. Low wort-nitrogen, especially when associated with high barley-nitrogen, indicates inadequate modification. There must be ample nitrogen in the wort to feed the yeast, and nitrogen compounds are also associated with the ability of beer to hold a good head of foam. On the other hand, too high a content of wort-nitrogen may lead to trouble in obtaining proper yeast-growth and a clear beer. The qualitative and quantitative aspects of this matter are not yet fully understood. If O.A.C. 21 is considered satisfactory with respect to wort-nitrogen and index of modification, then Olli gives values that are high, and Wisconsin and Regal give low values.

Attenuation measures the amount of fermentable material in the wort, and in this respect Olli and O.A.C. 21 are again superior to Velvet, and Velvet is far superior to Wisconsin and Regal. The initial turbidity of the wort and the final turbidity after standing for 24 hours should both be low. For initial turbidity, the order of the first three varieties is again Olli, O.A.C. 21, and Velvet. In final turbidity, Regal comes first, and this the writer and his colleagues have not been able to explain. Viscosity measures the extent of the degradation of starch and protein, and reflects the average size of the wort particles. It obviously depends on the activity of the amylases and proteases; low values appear desirable as they indicate a potential activity that can be controlled and reduced as required. The varieties again follow the order of their enzymatic activities—except for Regal, which gives a lower value than would be expected.

In the foregoing discussion, an attempt has been made to deduce from *a priori* premisses the properties that a good malting barley should have. The importance of high enzymatic activity has been stressed because of the short germination period employed in this continent and the wide use of starch adjuncts for certain types of beer. In Canada, particular emphasis is also laid on the extract yield of the malt, largely because the excise tax is placed on the malt itself rather than directly on the wort, as in England and the U.S.A. It is obvious that when the malt is taxed the price per unit of wort solids increases sharply with decreasing malt-extract. Considered from these viewpoints, the variety O.A.C. 21 has excellent malting properties, and merits its position as a standard. Olli would appear to be still better, except for its small size and low yield of plump kernels. These features, and the fact that it is confined largely to northern areas in Alberta and is not readily available in commercial amounts, have undoubtedly militated against its use by Canadian maltsters. It has excellent properties for the production of distiller's malt, especially in view of its high α-amylase activity [22], and should prove useful in the breeding-programme because of its high all-round enzymatic activity.

Although Wisconsin 38 is not considered a satisfactory malting barley in Canada, large quantities of this variety are malted in the U.S.A., and extensive studies of its properties have been made by Dickson and his co-workers at the University of Wisconsin [23, 24, and earlier papers]. It has not been compared with O.A.C. 21 but with a closely related variety, Oderbrucker, which is almost identical in malting properties. By the criteria already discussed, Wisconsin is considerably inferior to Oderbrucker in general malting properties. However, in the U.S.A. it has been possible to extend the studies to brewing trials [25, 26, 27]; and although one or two groups of judges have generally preferred beer made from Oderbrucker to beer made from Wisconsin 38, the available evidence suggests that the differences in brewing properties between these two varieties are not large.

The writer believes that the differences in malting properties between Wisconsin and such varieties as O.A.C. 21 and Oderbrucker are important. Owing to its high all-round enzymatic activity, O.A.C. 21 requires no forcing during the germination period. The barley has 'power'; there is something to control; and there is opportunity for the exercise of the maltster's art. The same arguments apply during kilning, and especially during mashing. When the enzymatic activity is present there is more scope for controlling processes and varying the quality of the products. And this will be particularly true when circumstances, such as the effect of an adverse growing season on the barley, are unfavourable.

It remains to consider why Wisconsin 38 is used for malting in the U.S.A. The old standard variety, Oderbrucker, was displaced during the prohibition era by the new, higher yielding, smooth-awned variety, Wisconsin 38; the farmers have naturally been loath to return to a barley that is poorer from their point of view; and the maltsters and brewers have been forced to use the barley that is available. That they have shown skill in adapting their methods to the new variety cannot be gainsaid; but it can hardly be disputed that they would prefer a better malting variety if there were one that the farmers could grow to advantage. The problem is in the hands of the barley breeders, and there is good reason to believe that it will be solved.

REFERENCES

1. T. J. Harrison and H. Rowland, *J. Inst. Brewing*, 1932, **38**, 502–8.
2. J. G. Dickson, H. L. Shands, A. D. Dickson, and B. A. Burkhart, *Cereal Chem.*, 1935, **12**, 596–609.
3. J. A. Shellenberger and C. H. Bailey, *Brewers' Tech. Rev.*, 1936, **11**, 3–5.
4. D. A. Colman, Experimental Malting at the U. S. Dep. Agric., *Int. Brewing Abstracts*, Aug., 1936.
5. J. A. Anderson, *Can. J. Research*, 1937, C, **15**, 204–216.
6. —— and H. Rowland, *Sci. Agric.*, 1937, **17**, 742–51.
7. —— and W. O. S. Meredith, Laboratory Malting. Pt. III. *Cereal Chem.*, 1940, **17**, 66–72.
8. W. O. S. Meredith, K. Hlynka, and H. R. Sallans, *Cereal Chem.* In press, 1944.
9. J. A. Anderson and H. R. Sallans, *Can. J. Research*, 1937, C, **15**, 70–7.
10. H. R. Sallans and J. A. Anderson, *Cereal Chem.*, 1937, **14**, 708–20.
11. C. A. Ayre and J. A. Anderson, *Can. J. Research*, 1939, C, **17**, 239–46.

12. W. O. S. MEREDITH and H. R. SALLANS, *Can. J. Research*, 1943, C, **21**, 351–62.
13. J. A. ANDERSON and W. S. O. MEREDITH, *Can. J. Research*, 1937, C, **15**, 242–51.
14. —— and H. R. SALLANS, *Can. J. Research*, 1938, C, **16**, 234–40.
15. H. R. SALLANS and J. A. ANDERSON, *Can. J. Research*, 1939, C, **17**, 57–71.
16. J. A. ANDERSON and W. O. S. MEREDITH, *Cereal Chem.*, 1937, **14**, 879–92.
17. ———— *Can. J. Research*, 1938, C, **16**, 248–52.
18. J. A. ANDERSON, H. R. SALLANS, and W. O. S. MEREDITH, *Can. J. Research*, 1941, C, **19**, 278–91.
19. ———— *Sci. Agric.*, 1943, **23**, 297–314.
20. H. R. SALLANS and J. A. ANDERSON, *Can. J. Research*, 1938, C, **16**, 405–16.
21. J. A. ANDERSON, C. A. AYRE, and W. O. S. MEREDITH, ibid., 1939, C, **17**, 25–34.
22. E. KNEEN, The Cereal Amylases. Significance of the Component Concept. *Wallerstein Lab. Comm.*, 1943, **6**, 101–10.
23. J. G. DICKSON, A. D. DICKSON, H. L. SHANDS, and B. A. BURKHART, *Cereal Chem.*, 1940, **17**, 495–504.
24. H. L. SHANDS, A. D. DICKSON, and J. G. DICKSON, ibid., 1942, **19**, 471–80.
25. Malt Research Institute, Industrial Evaluation of Two Barley Varieties, &c. *Malt Res. Inst.*, 1941, Pub. No. 1.
26. Ibid., 1942, Pub. No. 2.
27. Ibid., 1943, Pub. No. 3.
28. L. R. BISHOP, *J. Inst. Brewing*, 1930, **36**, 421–34.
29. —— Ibid., 1934, **40**, 75–91.
30. —— Ibid., 1936, **42**, 10–14.
31. —— and F. E. DAY, ibid., 1933, **39**, 545–51.
32. J. A. ANDERSON, H. R. SALLANS, and C. A. AYRE, *Can. J. Research*, 1938, C, **16**, 456–66.
33. H. R. SALLANS and J. A. ANDERSON, ibid., 1939, C, **17**, 361–72.
34. —— W. O. S. MEREDITH, and J. A. ANDERSON, ibid., 1941, C, **19**, 234–50.
35. ——and J. A. ANDERSON, ibid., 1940, C, **18**, 35–41.
36. ———— Ibid., 1940, C, **18**, 219–29.
37. W. O. S. MEREDITH, *Sci. Agric.*, 1943, **23**, 355–61.
38. —— H. R. SALLANS, and H. ROWLAND, ibid., 1942, **22**, 761–71.
39. T. J. HARRISON, ibid., 1929, **9**, 599–610.
40. A. T. ELDERS and H. ROWLAND, *J. Inst. Brewing*, 1933, **39**, 272–4.
41. J. A. ANDERSON and H. ROWLAND, *Sci. Agric.*, 1937, **17**, 593–600.
42. W. O. S. MEREDITH, H. ROWLAND, and J. A. ANDERSON, ibid., 1939, **19**, 389–403.
43. ———— and H. R. SALLANS, ibid., 1942, **22**, 584–93.
44. J. W. HOPKINS, ibid., 1936, **17**, 250–9.
45. W. O. S. MEREDITH, P. J. OLSON, and H. ROWLAND, ibid., 1942, **23**, 135–53.
46. J. G. MALLOCH, ibid., 1936, **16**, 289–321.
47. J. A. ANDERSON and T. R. AITKEN, *Seventeenth Annual Report*. Grain Research Laboratory, Board of Grain Commissioners for Canada, 1943.

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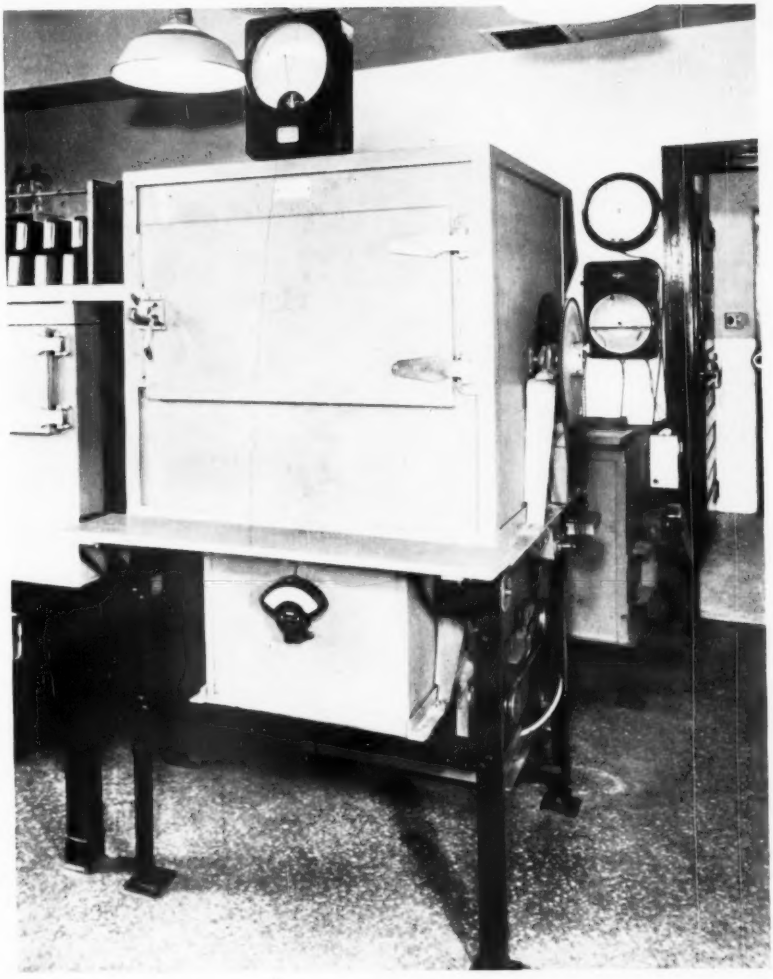

LABORATORY GERMINATION CHAMBER, FRONT VIEW

INDEX

Anderson, J. A., Canadian research on malting barley. I. Malting tests and qualities, 219–32.
Ashton, T., war-time feeding of concentrated food to pregnant rabbits, 51–3.

Barley, malting, Canadian research on. I. Malting tests and qualities, 219–32; determination of malt-yield and malt extract, 224; laboratory malting equipment, 220–4: germination unit, 223, kiln, 223–4, steep-tank, 221, 222–3; limitations of the malting test, 225–7; malting qualities of O.A.C. 21 and other varieties, 227–31.
Boyd, D. A., *see* Yates, F.

Cod-liver oil for pigs, alleged toxicity of, 74–82; experimental: dosage 75, pigs, 75, properties of oils, 76–7, rations, 75–6; results: live-weight gains, 77–9, post-mortem examinations, 79–80.
Coffee, robusta (*C. canephora*), root-systems of, in Uganda, 191–4, 198 sqq.; distribution and length of roots, 192–4; factors affecting development, 194–5; sampling methods, 191–3.
Coffees, the wild, of Uganda, 1–12, *C. canephora*, 3–8, *C. eugenioides*, 1–3, *C. excelsa*, 8–9, *C. spathicalyx*, 9–10; discussion, 10–12.

Davies, R. O., requirements of the potato on acidic bracken land, 54–60.

Eden, T., studies in the yield of tea. V. Further experiments on manurial response with special reference to nitrogen, 177–90.

Fagan, T. W., *see* Davies, R. O.
Farm crops, manuring of, in England, 163–76; conclusions, 175–6; crop-manuring diagrams, 170 (and inset after page 176); farmyard manure, 165–7, 168, 170; fertilizers, 167–71; relation between use of f.y.m. and fertilizers, 171–2; salt, 175; treatment of newly ploughed-out land, 172–5.
Feng, C. L., *see* Richardson, H. L.
Fertilizer practice in England, results of a survey of, 163–76.
Field experiment, efficiency of design in, 157–62; balanced incomplete blocks, 160–1; balanced lattices, 159–60; lattice designs, 158–9; lattice squares, 160; split-plot arrangements, 161.
French, M. H., development of livestock in Tanganyika Territory. VI. The development of mutton qualities in Masai and grade black-headed Persian sheep, 207–18.

Gold Coast, agriculture in the, 83–102; agricultural education, 96, 100, 101–2, marketing, 93–5, 99, policy, 96–100, 101, production, 90–3; cocoa, 86–9, 93–5, 97–8, 101; diseases and pests, 83, 87–8, 90, 92, 93, 95, 96, 97, 98, 99; food farming, 83–6, 96; land-planning, 95, 100, 101; progress to end of 1942, 100–2.
Grass covers in their relation to soil structure, 21–32; elephant grass, 21–5, 28; grass *v.* legumes, 28–9; rest and yield, 29–30.

Hammond, John, jnr., correction for time of service in lactation records for a fixed period, 154–6.
Hansen, R., *see* Shorland, F. B.
Hogan, K. J., *see* Shorland, F. B.
Hwang, S. T., *see* Richardson, H. L.

Imperial Agricultural Research Institute, New Delhi, wheat-breeding work at, 61–73.

John, J. L., *see* Davies, R. O.

Lactation records, correction for time of service for a fixed period, 154–6.
Livestock in Tanganyika, development of mutton qualities in Masai and grade black-headed Persian sheep, 207–18; age-changes in body composition, 207–9; composition of the joints, 211–16; relative weights of the joints in the carcasses, 209–11.
Lord, L., *see* Tempany, H. A.

Martin, W. S., grass covers in their relation to soil structure, 21–32.
Mathison, I., *see* Yates, F.
Miller, Wm. C., *see* Scorgie, N. J.
Moreau, R. E., yield and maturity period of potatoes at low latitudes, 13–20.

Pal, B. P., the Pusa wheats: the wheat-breeding work of the Imperial Agricultural Research Institute, New Delhi, 61–73.
Pig, bacon, effect of different feeding on iodine value of back fat, 103–19; experimental, 106–18; relations between iodine value and grade of pig, 117–18, growth-rate, 115, sex, 115–16.
Pigs, age-susceptibility to alleged toxicity of cod-liver oil for, 74–82.
Potato, requirements of the, on acidic bracken land, 54–60; calcium as nutrient, 55–6; composition and qualities of tubers, 57–60; effect of ground limestone on yield, 56–7.
Potatoes, yield and maturity period of, at low altitudes, 13–20; experimental evidence, 13–15; field data, 15–18.

Rabbits, war-time feeding of concentrated food to pregnant, 51–3.
Rice, use of organic and inorganic manures with (in China), 33–50; conclusions, 46–9; effects of compost, green manure, lime, night-soil, rape-seed cake, sulphate of

ammonia, on yields of grain and straw, 38–44; effects, residual, on rape seed, 44–5, 46; experimental details, 34–7; interactions, 40–1, 43, 46; rice stem-borer attack, 37, 41–3.
Richardson, H. L., use of organic and inorganic manures with rice: a continuous factorial experiment, 33–50.
Roddan, G. M., *see* Tempany, H. A.
Root-systems of robusta and other tropical crops in Uganda, 191–206; *C. canephora*, 191–5; cacao, cinchona, cotton, elephant grass, maize, other coffees, pigeon-pea, rubber, sugar-cane, tea, 195 sq.; cultivation effects, 199–200; lateral spread of roots, 198–9; planting, 198–9; root competition, 201–4; soil erosion, 204; soil permeability, 200–1.

Saunders, A. R., efficiency of design in field experiment at Potchefstroom, South Africa, 157–62.
Scorgie, N. J., further investigations on the alleged toxicity of cod-liver oil for pigs, 74–82.
Shorland, F. B., studies on the fats of the bacon pig with reference to carcass quality. I. Iodine value of the back fat under different conditions of feeding, 103–19.
Soil erosion and conservation in the Colonial Empire, 121–53; Africa: East, 123–32, 204, South, 132–6, West, 96, 136–9, High Commission Territories, 132–6; Eastern Dependencies, 141–3; Mediterranean Dependencies, 143–6; West Indies and America, 147–52; Western Pacific, 152.
Soil structure, grass covers in their relation to, 21–32; effect of cultivation, 25, of lime and manures, 25–8, of resting covers, 28–30; methods of assessing, 22–5.
Soils, bracken, redemption of, in Montgomeryshire, 54–9.
— coffee, in Uganda, 5, 8, 9, 11, 193; erosion of, 204; permeability, 200–1; sampling methods, 191–2.

Tea, response of, to manures, especially nitrogen, 177–90; effects of nitrogen, 178–84, 185–7, 188–9; of nitrogen after pruning, 180–3; of phosphoric acid, 178, 189; of phosphoric acid and potash, 184, 185; of potash, 177; of manures on composition of foliage-leaf, 187, 188.
Tempany, H. A., soil erosion and soil conservation in the Colonial Empire, 121–53.
Thomas, A. S., observations on the root-systems of robusta coffee and other tropical crops in Uganda, 191–206.
— the wild coffees of Uganda, 1–12.
Tsu, S. H., *see* Richardson, H. L.

Waters, H. B., agriculture in the Gold Coast, 83–102.
Wheat-breeding in India, 61–73; breeding for rust-resistance, 67–8, for smut-resistance, 68–9; cytological and genetical studies, 65, 66, 69–71; earlier investigations, 63–5; living collections, 66–7; physiological studies, 71.

Yates, F., the manuring of farm crops: some results of a survey of fertilizer practice in England, 163–76.
Yuan, S. H., *see* Richardson, H. L.